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FACTORS AFFECTING THE ABSORPTION[1] AND DISTRIBUTION OF AMMONIA APPLIED TO SOILS[2]

BY

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INTRODUCTION

As early as the sixteenth century it had been observed that coastal sands possessed the property of extracting salts from sea water. Since that time the purification of water by similar means has become a matter of such common observation that now it is hardly given a thought. And just as sands are able to retain dissolved matter, so soils in general act to a much larger extent as an immense reservoir in conserving plant-food that would otherwise be lost. It is therefore possible that many of the soil processes owe their effectiveness largely to this property of salt retention. The holding of soluble potash, phosphoric acid and nitrogen in soils against the leaching action of rains is a matter of economic importance and one that cannot well be overlooked. In fact, absorption by soils has been correlated with their crop-producing power and does undoubtedly bear some direct relation to soil fertility.

That this phenomenon is the resultant of numerous forces, and therefore very complicated, can hardly be disputed in view of the extensive, and often conflicting, observations which have been reported. In general, it has been the tendency to attribute the facts observed as due to simple causes acting independently of one another. Such factors as mechanical and chemical composition of soils, as well as hygroscopic moisture and colloids, some entirely chemical, others entirely physical, have been pointed out as possible explanations. Undoubtedly some, if not all of these, exert their influences, but from a study of the work following it seems clear that no one or two of these elements are wholly responsible.

[1] By the term "absorption" is meant the withdrawal from solution, without regard to whether it is due to physical, chemical or other causes.
[2] A thesis submitted to the faculty of Rutgers College in partial fulfillment of the requirements for the degree of Master of Science in Research, 1916.

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It has been suggested that absorption could be due to one, or more, of three causes: first, physical absorption; second, chemical absorption in the formation of an insoluble compound; or third, the "concentration of the dissolved substance on or about the surface of the absorbing medium" (5). The problem appears to be one for the physical chemist and will probably owe its complete solution to the full development of that field of science. At best, the work done at present must be largely superficial but may be justified as a contribution to the facts already known.

Broadly speaking, soil absorption manifests itself somewhat differently toward different materials. The absorption of phosphoric acid is undoubtedly controlled by factors different from those controlling that of potash or ammonia, while all three may have elements more or less in common. The work herein reported is limited to a study of that phase of absorption relating only to ammonia. In outlining the problem, it has been the desire of the writer to add something not only of scientific interest but also of practical significance in the use of ammonium sulfate as a fertilizer.

HISTORICAL

We are probably indebted to Way (30) for the first systematic researches upon the subject. He observed that when a solution of a salt was placed in contact with soil, a portion of the base, but none of the acid, was removed. In trying to determine which of the soil constituents was responsible, he passed a solution of ammonia through pure sand and found no change took place with this material. He then oxidized the organic matter of the soil with nitric acid and treated it with ammonia as before. Since no ammonia passed through the soil, he concluded that neither the organic matter nor the sand was essential to absorption. After numerous other tests he showed that with the soils used, clay was the main element causing the absorption phenomena. In attempting to trace out the particular compound which caused the absorption in the clay, he succeeded in producing a hydrated silicate of aluminum and soda which manifested absorptive properties similar to those of the soil. The addition of chalk to the soil in no way influenced the absorption of ammonia. Knop (15) confirmed this observation regarding lime.

It was shown by Eichorn (8) that natural hydrated silicates had the same power as Way's artificial preparation. Biedermann (3), Rautenberg (22) and Heiden (12) showed that the absorptive power bears a relation to the amount of soluble silicates contained. Tuxen (28) observed that the presence of salts of soda and potash in solution decreases the power of a salt to absorb ammonia. That hydrated oxides of iron and alumnia are capable of absorbing potash and ammonia was shown by Warington (29).

Armsby (2) points out that the absorption is accompanied by a chemical reaction between the salt whose base is absorbed and some constituent of the soil. He concludes from his own work and that of others that:

"1. The absorption of combined bases by the soil consists in an interchange of base between the salt and the hydrous silicates of the soil.

"2. This exchange, which is primarily chemical, is only partial, its extent varying

"(a) With the concentration of the solution, and

"(b) With the ratio between the volume of the solution and the quantity of the soil used.

"3. The cause of these variations is probably the action of mass or the tendency of the resulting compounds to reform the original bodies, the absorption actually found in any case marking the point where the two forces are in equilibrium."

Wiley (34) states that "it is now generally accepted that the absorption of salts of the alkalies, accompanied by the change of base, is due chiefly to the presence of decomposed zeolite minerals in the soil. Besides the purely chemical absorption of salts by the soil, we have a physical absorption of various substances similar to the action of charcoal when used as a filter."

Whitney (31) believes that the surface area of soils is largely responsible for their absorption properties. Huston (13) has calculated that an acre nine inches of soil will fix ammonia equivalent to more than 16,000 pounds of sulfate of ammonia, and that the problem is therefore of no practical significance.

Dittrich (7) shows that the absorption of ammonia is similar to that of potash, and that in both cases the union seems to be a chemical one.

In investigating the absorptive capacity of the different soil layers, Karpizov (14) found it at a maximum in the surface layer, decreasing directly with the humus and zeolites toward the deeper subsoil. The degree of absorption varied with the hygroscopic moisture content, carbonates, and to some extent with mechanical composition. Sabanin (25) confirms the observations of the relation of hygroscopic moisture and mechanical composition.

In certain Russian soils Zholtsinski (35) found also that hygroscopic moisture, mechanical composition and ammonia absorption bore a relationship to one another. The bulk of absorption was in the finest particles below .01 mm. diameter.

The presence of lime concretions was shown by Blanck (4) to have a marked effect upon the absorption in soils. Hall and Gimingham (11) found that when ammonium salts were in excess, a given weight of clay removed the same amount of ammonium from solution whatever the strength of the latter, if given time. Different constituent materials

of the soil, sand, clay, humus, and calcium carbonate, were tried for absorption. Sand gave negative results, while clay seemed mainly responsible. Humic acids were thought to form some insoluble compounds with ammonia. Calcium carbonate increased the absorption slightly.

Patten and Waggaman (20), having studied the subject of absorption very carefully, worked out a number of points in this connection. The mechanism of the process is studied and several formulae are derived to express certain functions, such as rate and extent of absorption in soils. The work is largely complementary to that referred to in the foregoing pages.

Morse and Curry (19) observed that clays react with potassium, sodium and ammonium in equivalent quantities. Calcium, magnesium, iron and aluminum constitute the largest amount of reacting bases. The extent of the reaction is dependent upon the concentration of the salt solution.

Rohland (23) and Wiegner (33) do not think the absorption chemical, but are inclined toward explaining it by a colloidal-physical theory. Pratolongo (21) divides the compounds of soils into solid solutions and absorptive compounds and uses this division as an aid in explaining the observed facts. The relation between the adsorption by soils and their hygroscopicity is shown again by Aberson (1). His experiments also indicated that "an equilibrium was established in the exchange of ions of the soil and of the added solution. The addition of ions which reacted with those in the solution reduced the adsorption. Soil adsorption followed the same law as adsorption by charcoal, wool, silk, etc. Adsorption in the soil is held to be a function of the surfaces of the colloidal substances."

Stoklasa (26) studied absorption in sterilized and unsterilized soils. Finding a difference in favor of the unsterilized soils, he concluded that there was a biological factor which may supplement those of a chemical or physical nature.

Lemmermann and Fresenius (16) worked chiefly with the volatilization of ammonia in soils, finding that $CaCO_3$ increased the absorption, while CaO had the opposite effect. KCl, NaCl, and sulfates and carbonates of these bases, as well as kainit and Thomas slag, reduced the absorptive power.

Wiegner (32) studied the exchange of bases when he used molecular equivalents of silicate gels, containing SiO_2, Al_2O_3, CaO, K_2O and H_2O. The absorption of ammonia liberated equivalent amounts of Ca and K ions. The influence of temperature was small; raising it caused a slight decrease in absorption. The degree of fineness of the silicate had but little effect upon absorption. Dehydration lessened it, at first only a little, but later reduced it to almost nothing.

Measurements of the absorption of ammonia on five soil types by Engles (9), at periods of 4 hours, 1, 8 and 14 days, showed practically no further increase after 4 hours. Absorption increased with lime, iron and alumina contents of the soils. Mitscherlich (18), after a thorough study of absorption by soils, concludes that solution and absorption constitute a cyclic process. Whether one or the other takes place will depend wholly upon the conditions present.

Crawley and Duncan (6) in attempting to locate the depth of soil which was responsible for the fixation of ammonia found that one-half of it was fixed in the first inch, four-fifths in the first two inches, and almost all in the first four inches.

McGeorge (17) found again that the absorption of ammonia was parallel to that of potash and corresponds in part to the amount of lime and magnesia present.

Gans (10) opposes the view of Wiegner that the phenomena of absorption are due to physical causes, and believes they are chiefly due to chemical ones instead. His beliefs are based upon the fact that aluminum silicate always absorbs the same amount of ammonia regardless of the concentration of the solution.

Tadskaro (27), in studying acid soils of Japan, finds that while the absorption of coloring matter follows very well the expansion and hygroscopic power (as functions of colloidal materials, supposedly), the absorption of ammonia does not. He believes that the fixation of ammonia represents more complicated conditions. Of the soils studied, the humus soils absorbed most ammonia, the clay soils the next largest amount, and the sandy soils least.

Ruprecht and Morse (24) show again that increase in concentration of the solution increases the absorption of ammonia, and that between limed and unlimed soils the former usually absorb the larger amount. They state that the absorption of ammonia is very similar to that of dyes, and believe that "the ammonia is held by physical rather than by chemical forces."

In reviewing the researches concerning this subject one cannot help being impressed by the extremely varied and conflicting observations reported. There appears to be ample evidence that the problem is a very complex one and that perhaps the apparent contradictions are only the result of different combinations of factors.

It is doubtful if any limited amount of work will wholly explain the mechanism of absorption of ammonia by soils, and the following is merely a contribution which may help somewhat in our understanding of it.

PURPOSE

In working upon the problem of ammonia fixation it was purposed to find, if possible, any additional information concerning the factors which

are responsible, as well as to learn more of what controls them. The application to several typical soil types of New Jersey was to be studied in particular, with its accompanying problems.

Considerable work has been done in connection with the method of application of ammonium sulfate to soils, with the result that many conflicting practices and theories have been brought out. A study of the vertical distribution of ammonia when applied to soils appeared to offer an opportunity of shedding some light upon this particular point.

PLAN

Samples of soil of widely differing character representing six prominent soil types of New Jersey were obtained. They are designated respectively by the Bureau of Soils of the U. S. Department of Agriculture, as Norfolk sand, Collington sandy loam, Sassafras loam, Dutchess silt loam, Penn loam, and Alloway clay.

The Norfolk sand, typical of a large area of coastal plains soils, is a very light soil low in organic matter. The Collington sandy loam was one which had been recently limed and is distinctly alkaline in reaction. It consists of moderately coarse sand and greensand marl with very little fine material. The Sassafras is a fairly heavy fertile loam. The Dutchess silt loam is a very heavy soil resembling the Penn loam in physical properties. The Alloway clay is a very stiff soil but is not as heavy as either the Dutchess silt loam or the Penn loam. As ordinarily classified the soils would be placed in the order suggested in the tables, but perhaps if arranged from lightest to heaviest, as indicted by the moisture-holding capacity, the order would rather be: Norfolk sand, Collington sandy loam, Alloway clay, Sassafras loam, Dutchess silt loam, and Penn loam.

EXPERIMENTAL

Part I

Absorption of Ammonia in Different Soil Types and some Factors Affecting It

Several methods have been devised for the determination of the absorptive capacity of soils, but so far the simple method used by Way in 1850 seems to be as satisfactory as any suggested. This method consists in the shaking of a given weight of soil in a flask with a given volume of a solution of known strength, allowing the mixture to stand until an equilibrium is reached and determining the concentration of the resultant solution. By difference in the solution strength the absorption is obtained. The objection has been raised to this method that it does not in any way approximate natural conditions and therefore the results cannot be applied. However true this may be, the other methods do not appear to possess any particular advantage.

But for the work in hand a comparison was made in order to see which one would be best suited for the purpose. The first consisted in shaking 50 gm. of soil for one minute with 200 c.c. of a 1/100 normal solution of sulfate of ammonia (34 mg. of ammonia), allowing to stand for a period and distilling off the ammonia from a filtered aliquot by the use of NaOH. The time of standing exerted some influence, as can be seen by referring to Table I. But the increase in absorption after 4 hours

TABLE I

ABSORPTION OF AMMONIA BY SOILS AS AFFECTED BY TIME[1]

Soil No.	1 Hour NH₃ Absor'd		2 Hours NH₃ Absor'd		4 Hours NH₃ Absor'd		24 Hours NH₃ Absor'd		48 Hours NH₃ Absor'd		72 Hours NH₃ Absor'd	
	Mg.	Av. Mg	Mg.	Av. Mg.	Mg.	Av. Mg.	Mg.	Av. Mg.	Mg.	Av. Mg.	Mg.	Av. Mg.
I	1.0	.....	1.0	.....	1.4	.....	1.0	.....	1.5	.....	[2]0.34	.....
	1.0	1.00	1.4	1.20	1.4	1.40	1.4	1.2	1.4	1.45	1.40	1.40
II	11.9	.....	12.6	.....	14.6	.....	14.6	.....	14.3	.....	14.90	.....
	11.2	11.55	11.6	12.10	13.9	14.25	13.9	14.25	14.6	14.45	14.60	14.75
III	8.2	.....	8.5	.....	9.2	.....	9.2	.....	9.2	.....	10.20	.....
	8.2	8.20	8.0	8.25	9.4	9.30	9.5	9.35	9.7	9.45	10.20	10.20
IV	5.4	.....	6.5	.....	7.8	.....	9.0	.....	8.8	.....	9.20	.....
	6.5	5.95	7.1	6.80	8.2	8.00	9.0	9.00	8.8	8.80	9.20	9.20
V	8.7	.....	9.9	.....	10.9	.....	11.0	.....	11.9	.....	11.90	.....
	8.3	8.50	9.0	9.45	10.9	10.90	11.7	10.35	11.4	11.65	12.60	12.75
VI	6.1	.....	6.1	.....	6.6	.....	6.5	.....	7.3	.....	7.80	.....
	5.4	5.75	6.5	6.30	6.3	6.50	6.5	6.50	7.1	7.20	7.51	7.65

[1] 200 c.c. of N/100 NH₃ solution added to 50-gm. portions of soil, shaken at intervals, and NH₃ determined in filtered aliquots.
[2] Omitted from average.

is small and seems to confirm Engel's observation in this respect. This period was therefore chosen for the remainder of the work.

The second method consisted in placing 50 gm. of soil upon a folded filter and adding 8 c.c. (136 mg. NH₃) of a normal ammonium sulfate solution. After bringing the soil to optimum moisture conditions it was allowed to stand for 4 hours and leached with distilled water. In order to determine how much water was necessary to use in getting the fixation, a preliminary test was run. Consecutive 200-c.c. portions of the filtrate were collected and examined for ammonia. The results are shown in Table II.

Practically all of the ammonia that was recovered in the leachings was washed out in the first 200 c.c.; undoubtedly the addition indefinitely of more water to the soil would continue to bring out small amounts of ammonia. For the present purposes, however, 600 c.c. appeared to be sufficient. Soil No. II showed a rather interesting behaviour in that it continued to give out the most ammonia after the first 200 c.c. had passed

through the soil. Throughout the whole work this soil shows exceptional characteristics of which special note should be taken. The ammonia fixed in the soil was determined by distillation with magnesium oxide. The amounts obtained are shown in the table, together with the total recovery.

TABLE II
RECOVERY OF AMMONIA ADDED TO SOIL[1]

Soil No.	1st 200 c.c. Ammonia		2nd 200 c.c. Ammonia		3rd 200 c.c. Ammonia		4th 200 c.c. Ammonia		5th 200 cc. Ammonia		% NH$_3$ in 1000 c.c. Av.	In Soil Ammonia		Total % Recovery
	Mg.	Av. Mg.	Mg.	Av. Mg.	Mg.	Av. Mg.	Mg.	Av. Mg.	Mg.	Av. Mg.		Av. Mg.	Mg.	
I	125.0	.....	1.4	....	1.0	....	0.8	....	0.4	....	....	1.0	....	....
	126.0	125.5	1.2	1.3	1.7	1.4	1.4	1.1	0.4	0.4	94.7	1.6	1.3	95.4
II	88.5	.....	4.1	....	2.5	....	2.4	....	2.1	....	....	23.5	....	....
	93.5	91.0	4.6	4.4	2.4	2.5	2.5	2.5	2.1	2.1	75.4	23.5	23.5	92.7
III	116.0	.....	3.6	....	1.7	....	1.2	....	1.0	....	....	8.8	....	....
	112.0	114.0	2.5	3.1	1.2	1.5	1.0	1.1	0.7	0.9	88.8	9.8	9.3	95.4
IV	116.0	.....	2.5	....	2.4	....	1.2	....	0.8	....	....	7.5	....	....
	114.0	115.0	2.7	2.6	1.2	1.8	0.8	1.0	0.8	0.8	89.2	7.4	7.5	94.6
V	109.0	.....	2.4	....	1.0	....	1.0	....	0.7	....	....	13.0	....	....
	102.0	105.5	4.0	3.2	1.2	1.1	1.0	1.0	0.7	0.7	81.4	13.0	13.0	91.9
VI	119.0	.....	2.2	....	1.0	....	0.8	....	0.7	....	....	7.5	....	....
	117.0	118.0	2.2	2.2	0.8	0.9	0.8	0.8	0.5	0.6	90.2	7.1	7.3	95.6

[1] 50-gm. portions of soil, 8 c.c. N/1 NH$_3$ added, brought to optimum moisture, stood 1 hour and leached, 136 mg. NH$_3$ added.

Not all the ammonia added was recovered, the percentage varying with the soils, as would be expected. Whether the absorption could best be determined by distilling off the ammonia "fixed" in the soil or by getting that in the filtrate was the next point studied.

TABLE III
RECOVERY OF AMMONIA ADDED TO DIFFERENT SOILS[1]

Soil No.	I		II		III		IV		V		VI	
	NH$_3$ Found		NH$_3$ Found		NH$_3$ Found		NH$_3$ Found		NH$_3$ Found		NH$_3$ Found	
	Mg.	Av. Mg.	Mg.	Av. Mg.	Mg.	Av. Mg.	Mg.	Av. Mg.	Mg.	Av. Mg.	Mg.	Av. Mg.
	16.1	.....	16.3	.....	15.8	.....	14.2	.....	15.3	.....	15.3	.....
	16.1	16.1	16.5	16.4	15.7	15.75	13.9	14.05	14.9	15.1	15.4	15.35
% Recov'd	.....	95.0	.....	96.5	.....	92.80	.....	82.7	.....	88.8	.....	90.3

[1] 1 c.c. N/1 NH$_3$ added to 50 gm. soil, allowed to stand 4 hours and NH$_3$ distilled off; 17 mg. NH$_3$ added.

In Table III the recovery of ammonia added is tabulated. It is seen that the recovery varies widely with the soil, indicating that the determination of the ammonia in the filtrate would probably be the most satisfactory criterion of the absorption.

Having settled the minor considerations, a comparison of the two methods was carried out, 50 gm. of soil and 34 mg. of NH_3 being used in each case. The ammonia after standing in contact with the soil for 4 hours was determined in a filtered aliquot of the solution from the flask in the first method. In the second, the ammonia was determined in 200 c.c. of the first 600 c.c. of the leachings. The absorption was calculated and recorded in Table IV.

TABLE IV

COMPARISON OF THE ABSORPTION OF AMMONIA BY SOIL IN FLASKS AND UPON FILTERS

Soil No.	Lab. No.	50 gm. 200 c.c. N/100 NH_3 in flasks Ammonia Absorbed		Lab. No.	50 gm. 2 c.c. N/1 NH_3 on filters Ammonia Absorbed	
		Mg.	Av. Mg.		Mg.	Av. Mg.
I	157	1.4	.....	169	4.4	.....
	158	1.4	1.40	170	2.4	3.40
II	159	14.6	.....	171	16.6	.....
	160	13.9	14.25	172	18.0	17.30
III	161	9.2	.....	173	11.8	.....
	162	9.4	9.30	174	11.8	11.80
IV	163	7.8	.....	175	9.5	.....
	164	8.2	8.00	176	9.8	9.65
V	165	10.9	.....	177	11.5	.....
	166	10.9	10.90	178	14.1	12.80
VI	167	6.6	.....	179	8.5	.....
	168	6.3	6.45	180	8.5	8.50

The individual results are for the most part much more uniform in the series in which the flasks were used. It is true that a somewhat higher absorption is indicated with the second method, but the difference does not seem to be great enough to be a decided point in its favor, and it is fully

TABLE V

ABSORPTION OF AMMONIA BY SOILS

Soil	Mg. NH_3 per 50 gm. Soil	Pounds $(NH_4)_2SO_4$ per Acre
I. Norfolk sand	1.4	266
II. Collington sandy loam	13.9	2645
III. Sassafras loam	9.0	1710
IV. Dutchess silt loam	8.0	1520
V. Penn loam	10.5	1990
VI. Alloway clay	6.8	1290

counter-balanced by the lack of uniformity in the cases of Soils I, II and V. With one exception, the remainder of the work was carried out according to the first method.

It is natural to expect certain wide absorption ranges among soils of widely differing characters. We would undoubtedly expect that, other things being equal, the heavier the soil the greater would be its absorptive capacity. That this is true to a certain extent has been observed, but

just what is the absorptive power of a specific soil can be determined only by trial. In Table V the relative absorption of ammonia is recorded both per 50 gm. of soil and per acrè 6 2/3 inches (2,000,000 pounds of soil). With the exception of Soil I, the absorption by all soils appears to be sufficiently great that it would not be a factor of practical importance. The indication is undoubtedly a true one that very little nitrogen, as ammonia, would be leached out of any of the rest of these soils.

But the problem has a broader bearing than this, inasmuch as high absorptive powers of soils usually indicate high fertility. Following in the same manner that of potash, the absorption of ammonia probably is more truly indicative of the fertility of a soil than the absorption of phosphoric acid, since the absorption of the latter is largely due to the formation of insoluble compounds with iron and alumina. Most soils, even relatively infertile ones, possess enough of these constituents to absorb considerable quantities of phosphoric acid.

TABLE VI

MECHANICAL ANALYSIS OF SOILS

Soil	Organic Matter	Gravel 2-1 mm.	Coarse Sand 1-.05 mm.	Medium Sand .5-.25 mm.	Fine Sand .25-.1 mm.	Very Fine Sand .1-.05 mm.	Silt .05-.005 mm.	Clay .005 mm.
	%	%	%	%	%	%	%	%
I. Norfolk sand[1]	0.10	4.32	26.90	29.80	33.84	1.86	2.40	0.74
II. Collington sandy loam[1]..	1.07	1.34	8.64	27.84	35.62	15.24	7.22	3.86
III. Sassafras loam[1]	1.45	2.26	8.28	6.30	9.94	10.08	53.38	8.80
IV. Dutchess silt loam[2]......	....	2.90	4.10	3.10	10.00	17.30	45.40	17.00
V. Penn loam[1]	2.39	1.48	3.22	2.78	5.86	13.12	61.42	11.46
VI. Alloway clay[1]	3.46	1.18	3.52	3.80	5.42	5.84	53.80	25.30

[1] Soil survey of the Trenton area, New Jersey. U. S. Dept. Agr. Field Operations Bur. Soils, 1902, p. 163-186.

[2] The mechanical and chemical composition of the soils of the Sussex area, New Jersey. Geol. Surv. N. J. Bul. 10, 1913.

A wide range of absorption is noted in Table V, the least occurring in the lightest soil, the Norfolk sand, and the most, not in the heaviest soil, but in the next lightest, the Collington sandy loam. The soils may be arranged according to their absorptive capacity from the greatest to the least as follows: II, V, III, IV, VI, I. That the Collington (Soil II) should occupy first place seemed almost inexplicable.

It was thought that possibly the mechanical and chemical analyses[1] of the respective soil types might aid in explaining the relative positions of the soils. Table VI, giving the mechanical analyses, apparently offers no clue, for there does not seem to be a single correlation between the absorption noted and any of the factors given in the table. But by barring

[1] Analyses of the soils were not made, since they represented common types of which analyses were available.

Soil II the general tendency appears to show greater absorption in the heavier soils, although it seems evident that the mechanical composition can have only a minor influence. In the earlier work, where a correlation between this and the absorptive capacity appeared to hold, it is believed that other more important and potent elements were absent.

That absorption may take place even in such inert material as pure quartz sand is shown in Table VII. The only necessary condition to this apparently physical phenomenon is a fine state of division.

No absorption of ammonia could be detected up to 30-mesh sand when only 0.3 mg. was fixed; even in the finest quartz flour the absorption was small. Since quartz sand is probably the most resistant mineral in soils, it is doubtful if it reaches so fine a state of division in sufficient quantities to affect their absorptive properties to any extent. But it is not impossible that some of the absorption may be traced to this element.

TABLE VII
ABSORPTION OF AMMONIA BY SAND

Lab. No.	Fineness	Ammonia Absorbed	
		Mg.	Av. Mg.
181	16 mesh	0	...
182	16 mesh	0	0
183	24 mesh	0	...
184	24 mesh	0	0
185	30 mesh	.3	...
186	30 mesh	.3	.3
187	80 mesh	1.0	...
188	80 mesh	1.0	1.0
189	I5 XX bolting	2.0	...
190	Cloth	2.0	2.0

It is, however, quite possible and even probable that of two soils having like chemical constitution, the heavier one would manifest greater absorptive power.

Correlations between absorption and iron, alumina, calcium, magnesium, and carbon dioxide contents have frequently been pointed out. In Table VIII we find that in order of iron and alumina content the soils arrange themselves from highest to lowest in the following manner: V, IV, III, VI, II, I. By eliminating Soil II and interchanging Nos. III and IV, which show very close values, we get them in the order of their absorptive capacities. Whether this correlation is accidental or not, there still seems to be some relationship.

But with reference to calcium we find the order, II, V, III, IV, VI, I, and here we have the exact order of their absorptive powers. The presence of CaO then seems to affect strongly this property of soils.

Taking magnesia next, we find the order IV, V, VI, III, II, I, in which there seems to be no relationship. With carbon dioxide we get the following arrangement: III, IV, V, II, VI, I. The order III, IV, VI, I

correlates very nicely, but the position of II and V rather invalidates this as any indication. With reference to the alkalies the order is: V, IV, III, VI, II, I, to which no significance is attached. According to the percentage of organic matter the soils are placed: V, IV, III, VI, II, I, which is the same order as the iron and alumina content and follows the absorption in the same manner.

TABLE VIII

CHEMICAL ANALYSIS OF SOILS

	I Norfolk[1] Sand %	II Colling'n[1] Sandy Loam %	III Sassafras[1] Loam %	IV Dutchess[2] Silt Loam %	V Penn[1] Loam %	VI Alloway[3] Clay %
Insoluble Matter	93.67	93.56	86.84	80.07	76.99	88.28
Soluble Silica	.01	.04	.03	.062	.08	.09
K_2O	.02	.07	.19	.315	.78	.17
Na_2O	.05	.05	.12	.057	.29	.08
CaO	.04	[4].28	.20	.107	.23	.06
MgO	.05	.05	.17	.910	.84	.22
Mn_3O_4	.02	.01	.03	.065	.08	.05
Fe_2O_3	1.96	1.32	2.51	3.917	4.02	2.12
Al_2O_3	.63	1.07	3.88	5.707	7.18	3.72
P_2O_5	.05	.133	.158	.186	.118	.08
SO_3	.05	.02	.08	.060	.04	.06
CO_2	.01	.025	.05	.034	.03	.024
Volatile Matter	3.08	3.27	5.75	6.21	9.24	4.98

[1] Lipman, J. G., and Blair, A. W. Investigations relative to the use of nitrogenous plant foods, 1898-1912. N. J. Agr. Exp. Sta. Bul. 288, 1916.

[2] The mechanical and chemical composition of the soils of the Sussex Area, New Jersey. Geol. Surv. N. J. Bul. 10, 1913.

[3] Lipman, J. G., and Blair, A. W. Field experiments on the availability of nitrogenous fertilizers. N. J. Agr. Exp. Sta. Bul. 260, 1913.

[4] Owing to the fact that this soil had been limed, the calcium was determined and substituted for the value given.

By way of chemical composition, then, it perhaps may be said of the six soils used, that there is a close relationship between the lime content and the absorption of ammonia. There exist also more or less close parallels between the contents of magnesia, alkalies, iron and alumina, carbon dioxide, and volatile matter, but these are perhaps less vital than other factors in determining the soil's absorptive power.

As a further effort to learn if hygroscopic moisture, apparent specific gravity, water-holding capacity, or lime requirement bore any relation to the absorption of ammonia, these were determined and the results given in Table IX.

No direct relationship can be assigned to these factors except in a general way. For instance, the smallest amount of hygroscopic moisture is shown by Soil I, having the least absorption, and the largest amount, barring Soil II, is shown by Soil V, having the greatest absorption.

Roughly the absorption is inversely proportional to the apparent specific gravity and proportional to the water-holding capacity with the one exception. All the soils, except No. II, shows a lime requirement. This fact at once seemed to afford a possible explanation of its peculiar behavior which resulted in its occupying first place with reference to its absorptive power.

TABLE IX

HYGROSCOPIC MOISTURE, APPARENT SPECIFIC GRAVITY, WATER-HOLDING
CAPACITY AND LIME REQUIREMENT OF SOILS USED

	I	II	III	IV	V	VI
Soil No.	Norfolk Sand	Colling'n Sandy Loam	Sassafras Loam	Dutchess Silt Loam	Penn Loam	Alloway Clay
Hygroscopic Moisture, %...	.15	1.60	1.31	1.87	2.28	.88
Apparent Specific Gravity...	1.52	1.34	1.18	1.16	1.10	1.30
Water-Holding Capacity, %.	.34	.42	.49	.54	.55	.44
Lime Requirement—lbs. CaO per 2,000,000 lbs. soil....	550	Alkaline	1400	2200	1500	1200

If, then, the fact that the reaction of one soil was basic was responsible for its superior absorptive capacity, there seemed to be no reason why the addition of lime to the other soils should not decidedly raise their absorption.

TABLE X

EFFECTS OF CaO AND CaCO₃ UPON ABSORPTION OF AMMONIA

Soil No.	No Treatment Ammonia Absorbed			0.1 gm. CaO to 50 gm. Soil Ammonia Absorbed				0.2 gm. CaO₃ to 50 gm. Soil Ammonia Absorbed			
	Lab. No.	Mg.	Av. Mg.	Lab. No.	Mg.	Av. Mg.	Increase Av. Mg.	Lab. No.	Mg.	Av. Mg.	Increase Av. Mg.
I	227	1.4	......	275	3.7	......	......	287	3.4	......	......
	228	1.4	1.4	276	4.4	4.05	2.65	288	3.7	3.55	2.15
II	229	13.9	......	277	10.2	......	......	289	14.6	......	......
	230	13.9	13.9	278	10.2	10.2(	—3.70	290	14.6	14.60	0.70
III	231	8.8	......	279	11.9	......	......	291	9.9	......	......
	232	9.2	9.0	280	11.7	11.80	2.80	292	9.9	9.90	0.90
IV	233	8.2	......	281	11.4	......	......	293	9.3	......	......
	234	7.8	8.0	282	11.5	11.45	3.45	294	8.7	9.00	1.00
V	235	10.5	......	283	12.9	......	......	295	11.2	......	......
	236	10.5	10.5	284	11.9	12.40	2.35	296	......	11.2	0.70
VI	237	6.5	......	285	9.5	......	......	297	7.5	......	......
	238	7.1	6.8	286	9.9	9.70	2.90	298	7.5	7.5	0.70

Accordingly 0.1 gm. of CaO was added to one set of soils and 0.2 gm. CaCO₃ was added to another set, and the absorption determined as previously indicated. In Table X the results are recorded and figure 1 shows graphically the effect of the former. The addition of calcium carbonate, while serving to increase slightly the capacity of all soils to absorb am-

monia, was not marked in its action and would lead us to believe that it does not function actually in the absorption process.

In the case of the calcium oxide, however, we can note a decided increase in the soils' absorptive capacity for ammonia in every case but one, that of No. II. Why this soil should behave in this manner was not at first clear. It seemed reasonable to suppose that even though there was some free CaO in the soil before, the addition of more would strengthen its absorptive power. But since this was not the case, the only evident explanation seemed that there was possibly an over-abundance of the element in the soil already. This might tend to indicate that there is a point with every soil where the addition of CaO would effect a lowering of its absorptive capacity.
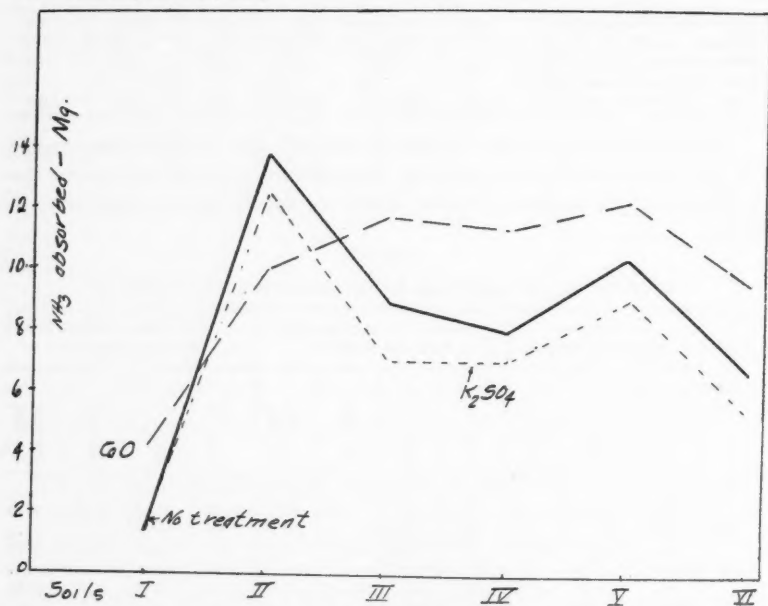
Fig. 1.—Diagram showing the effect of CaO and K_2SO_4 upon the absorption of ammonia.

Quantities of CaO ranging from 0.1 gm. up to 0.5 gm. were added to each soil and the absorption again noted. The results are shown numerically and graphically in Table XI and figure 2.

Exactly what we anticipated took place. There is shown at first in every case but that of Soil II, an increase in the absorptive capacity followed by a subsequent steady decrease. It is interesting to see that the absorption of Soil II decreases in almost a straight line until with 0.3 gm. CaO it absorbs only as much as Soil I, that is, the least amount; that this

reaches a constant with both soils below which it does not go is indicative, perhaps, that with a certain lime-content all the soils may finally reach a similar constant. The presence of lime, then, in sufficient quantities[1] almost paralyzes the absorption mechanism. At any rate it shows that even it alone can be a limiting factor before which all others must give way. But it is doubtless true that in most soils little if any calcium would be present as CaO and the absorption in these soils must be due principally to other causes. This fact serves to strengthen the writer's view that the process is a very complicated one where one factor, in the absence of others, may be responsible for the bulk of the absorption.

TABLE XI

EFFECT OF INCREASING AMOUNTS OF CaO UPON THE ABSORPTION OF AMMONIA BY SOILS

Gm. CaO per 50 gm. Soil	Soil I				Soil II				Soil III			
	Lab. No.	Ammonia Absorbed			Lab. No.	Ammonia Absorbed			Lab. No.	Ammonia Absorbed		
		Mg.	Av. Mg.			Mg.	Av. Mg.			Mg.	Av. Mg.	
None	299	1.4	.....	Inc. due to	311	12.9	.....	Inc. due to	323	8.5	.....	Inc. due to
None	300	1.4	1.4	CaO	312	12.9	12.9	CaO	324	8.5	8.5	CaO
0.1	301	2.4	.....	.....	313	9.5	.....	.....	325	10.9	.....	.....
0.1	302	2.0	2.2	0.8	314	9.5	9.5	—3.4	326	10.7	10.8	2.3
0.2	303	1.7	.....	.....	315	5.4	.....	.....	327	11.0	.....	.....
0.2	304	1.7	1.7	0.3	316	4.8	5.1	—7.8	328	11.0	11.0	2.5
0.3	305	1.7	.....	.....	317	1.7	.....	.....	329	9.9	.....	.....
0.3	306	1.7	1.7	0.3	318	1.7	1.7	—11.2	330	9.9	9.9	1.4
0.4	307	1.7	.....	.....	319	1.7	.....	.....	331	8.5	.....	.....
0.4	308	1.7	1.7	0.3	320	1.7	1.7	—11.2	332	8.5	8.5	0.0
0.5	309	1.7	.....	.....	321	1.7	.....	.....	333	6.6	.....	.....
0.5	310	1.7	1.7	0.3	322	1.7	1.7	—11.2	334	6.8	6.7	—1.8

Gm. CaO per 50 gm. Soil	Soil IV				Soil V				Soil VI			
None	335	7.8	.....	.....	347	9.5	.....	.....	359	6.8	.....	.....
None	336	7.2	7.5	.....	348	9.7	9.6	.....	360	6.6	6.7	.....
0.1	337	10.6	.....	.....	349	11.8	.....	.....	361	9.5	.....	.....
0.1	338	11.2	10.4	2.9	350	12.2	12.0	2.4	362	9.5	9.5	2.8
0.2	339	11.8	.....	.....	351	13.5	.....	.....	363	8.5	.....	.....
0.2	340	11.2	11.5	4.0	352	13.3	13.4	3.8	364	8.5	8.5	1.8
0.3	341	11.8	.....	.....	353	12.6	.....	.....	365	6.8	.....	.....
0.3	342	11.0	11.4	3.9	354	12.8	12.7	3.1	366	6.6	6.7	.0
0.4	343	10.5	.....	.....	355	11.8	.....	.....	367	4.8	.....	.....
0.4	344	10.9	10.7	3.2	356	11.6	11.7	2.1	368	5.2	5.0	—1.7
0.5	345	9.6	.....	.....	357	11.1	.....	.....	369	4.1	.....	.....
0.5	346	8.8	9.2	1.7	358	10.9	11.0	1.4	370	4.1	4.1	—2.6

Flocculation and deflocculation in soils form a basis for the discussion of the problem from another standpoint. It is well known that deflocculation follows the excess of soluble bases in the soil which tend toward favoring the presence of large amounts of colloidal material; on the other hand, the presence of acids usually indicates a minimum of colloids,

[1] With the larger amounts of CaO used some volatilization of ammonia took place, but in no case did it exceed 2 mg.

owing to hydrolysis. The supporters of the colloidal theory of absorption have laid considerable stress upon this point. The matter of reaction is therefore a point to be considered.

Table XII with figure 3 shows the effect upon absorption of a small amount of acid and alkali, 2 c.c. of normal HCl being added to one series of soils and 2 c.c. normal NaOH to the other series.
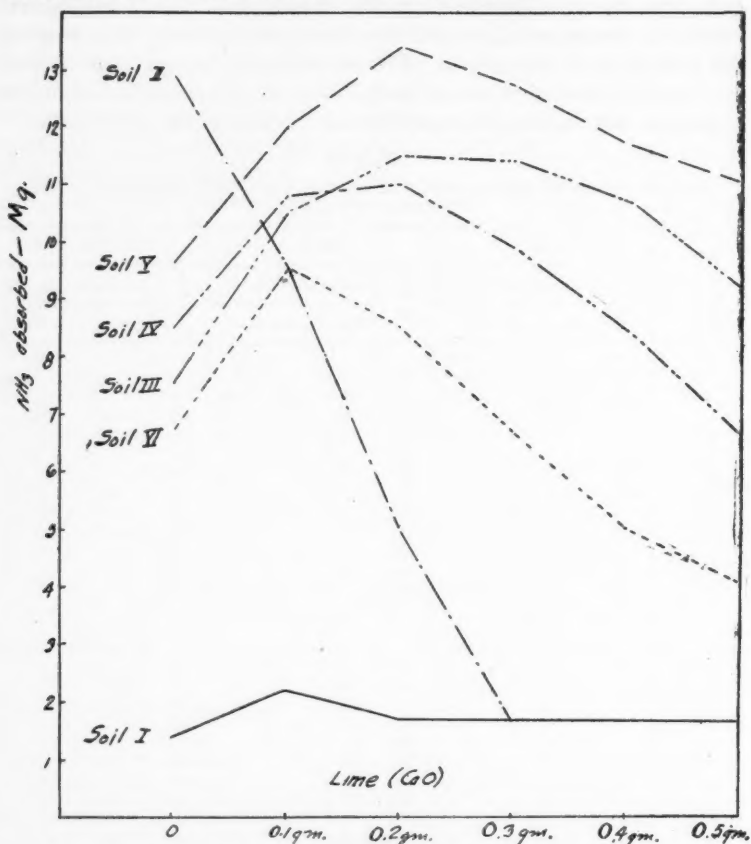
Fig. 2.—Diagram showing the effect of increased amounts of CaO upon the absorption of ammonia.

In every case we get a fairly large increase due to the presence of NaOH. This is undoubtedly because of the deflocculating effect of the base in the probable formation of colloids such as $Fe(OH)_3$, $Al(OH)_3$, various silicates and numerous others. That this increase is largely due to the formation of colloidal iron and alumina is indicated by the fact that the increase is marked in Soil I, where there is very little clay and

TABLE XII

EFFECT OF SODIUM HYDROXIDE AND HYDROCHLORIC ACID ON ABSORPTION OF AMMONIA

| Soil No.	No Treatment Ammonia Absorbed			2 c.c. Normal NaOH Ammonia Absorbed				2 c.c. Normal HCl Ammonia Absorbed			
	Lab. No.	Mg.	Av. Mg.	Lab. No.	Mg.	Av. Mg.	Increase Av. Mg.	Lab. No.	Mg.	Av. Mg.	Increase Av. Mg.
I	227	1.4	......	251	6.1	......	......	263	0.2	......	......
	228	1.4	1.4	252	6.1	6.10	4.70	264	0.3	0.25	—1.15
II	229	13.9	......	253	11.6	......	......	265	9.5	......	......
	230	13.9	13.9	254	12.2	11.90	2.00	266	9.9	9.70	—4.20
III	231	8.8	......	255	15.3	......	......	267	4.1	......	......
	232	9.2	9.0	256	15.0	15.15	6.15	268	4.1	4.10	—4.90
IV	233	8.2	......	257	15.6	......	......	269	2.4	......	......
	234	7.8	8.0	258	15.3	15.45	7.45	270	3.1	2.75	—5.25
V	235	10.5	......	259	16.3	......	......	271	5.5	......	......
	236	10.5	10.5	260	17.3	16.80	6.30	272	4.4	4.95	—5.55
VI	237	6.5	......	261	11.2	......	......	273	1.7	......	......
	238	7.1	6.8	262	8.8	10.0	3.20	274	2.4	2.05	—4.75
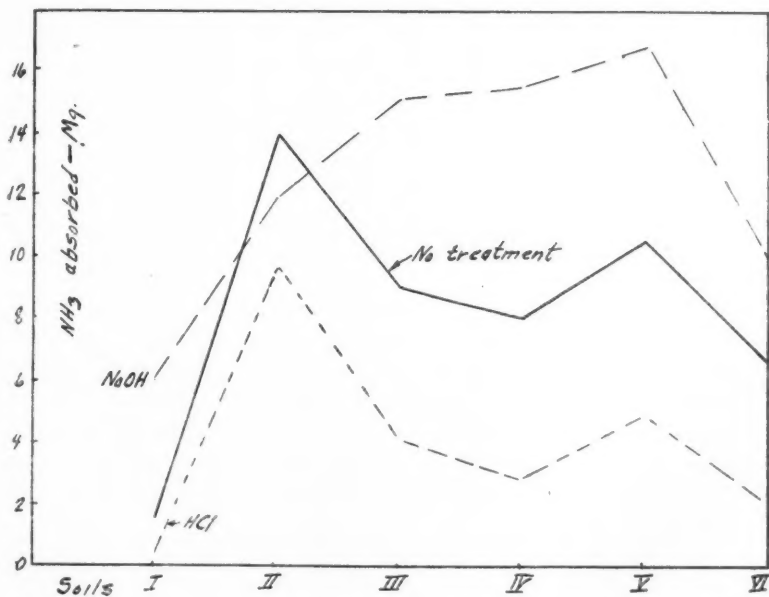
Fig. 3.—Diagram showing the effect of reaction of solution upon the absorption of ammonia.

(ii—23)

the soil consists almost entirely of silica, iron and alumina. The lowest increase, it is noted, is for the soil having the lowest lime requirement (basic), and the largest increase for the soil having the highest lime requirement.

Just as we obtained an increase in the absorptive capacity by the introduction of NaOH, in the same way we get a decrease in every case by the use of HCl. This may be due to the hydrolysis of the soil colloids as well as to the neutralization of any bases that might have been present.

TABLE XIII

EFFECT OF WASHING OUT WATER-SOLUBLE AND ACID-SOLUBLE[1] MATTER UPON ABSORPTION OF AMMONIA BY SOILS UPON FILTERS

Soil No.	Ammonia Absorbed No Treatment			Ammonia Absorbed Leached with 600 c.c. H$_2$O				Ammonia Absorbed 25 c.c. N/1 HCl + 500 c.c. H$_2$O			
	Lab. No.	Mg.	Av. Mg.	Lab. No.	Mg.	Av. Mg.	Increase Av. Mg.	Lab. No.	Mg.	Av. Mg.	Increase Av. Mg.
I	191	2.9	......	203	3.4	......	......	215	1.6	......	......
	192	4.5	3.70	204	3.7	3.55	—0.15	216	2.6	2.10	—1.60
II	193	15.9	......	205	19.7	......	......	217	11.8	......	......
	194	17.2	16.55	206	21.7	20.70	4.15	218	11.6	11.70	—4.85
III	195	10.8	......	207	......	......	......	219	2.9	......	......
	196	10.8	10.80	208	10.5	10.50	—0.30	220	4.4	3.65	—5.15
IV	197	13.1	......	209	12.1	......	......	221	7.0	......	......
	198	9.9	11.50	210	10.5	11.30	—0.20	222	9.2	8.10	—3.40
V	199	14.1	......	211	16.1	......	......	223	8.0	......	......
	200	13.6	13.85	212	16.6	16.35	2.50	224	6.0	7.00	—6.85
VI	201	8.0	......	213	9.5	......	......	225	[2]0.1	......	......
	202	9.0	8.50	214	9.5	9.50	1.00	226	3.4	3.40	—5.10

[1] 25 c.c. normal HCl added to 50 gm. soil in flasks, digested on a water bath for 1 hour, and leached with 500 c.c. distilled water.
[2] Omitted from average.

It was thought that by washing out the water-soluble and acid-soluble matter from the soils, the causes of absorption might be further limited. In Table XIII the results of treating with 600 c.c. of distilled water and also by digestion with 25 c.c. normal HCl for an hour, filtering and washing, are presented. It is realized that very little of the soluble salts would be leached out in so small a quantity of water, yet it seemed to offer another point of attack.

In this experiment the leaching method was used to determine the absorption. It will be noted that in three cases the absorption is greater after leaching than before; while there is a slight decrease in the other three instances, this may well be within the limits of error. At any rate the absorption does not appear to be impaired, but rather enhanced. It is perhaps allowable to say that absorption is not increased by the presence of easily soluble salts.

However, the loss of acid-soluble salts including the hydrolyzable colloids appreciably decreased the absorptive powers of the soils. It is to be noted by comparison with Table XII that the decrease in absorption is much more marked, a condition due probably as much to the greater amount of acid used as to the removal of the salts from the soil.

The digestion with acid was repeated, 50 c.c. of concentrated HCl and 50 gm. of soil being used. After allowing the extraction to take place on the water bath for 2 hours the acid was decanted off and the soil was washed upon a filter with 500 c.c. of water. The absorption was determined in the flasks as usual. The results are given in Table XIV.

TABLE XIV

EFFECT OF REMOVAL OF ACID-SOLUBLE MATTER UPON ABSORPTION OF AMMONIA BY SOILS

Soil No.	No Treatment			Treatment[1]			Decrease due to Treatment
	Lab. No.	Ammonia Absorbed		Lab. No.	Ammonia Absorbed		
		Mg.	Av. Mg.		Mg.	Av. Mg.	Av. Mg.
I	227	1.4	....	239	0.7	....	....
	228	1.4	1.4	240	0.7	0.70	0.70
II	229	13.9	....	241	9.5	....	....
	230	13.9	13.9	242	9.2	9.35	4.65
III	231	8.8	....	243	2.4	....	....
	232	9.2	9.0	244	2.7	2.55	6.45
IV	233	8.2	....	245	2.0	....	....
	234	7.8	8.0	246	2.0	2.00	6.00
V	235	10.5	....	247	1.7	....	....
	236	10.5	10.5	248	2.4	2.05	8.45
VI	237	6.5	....	249	1.7	....	....
	238	7.1	6.8	250	1.7	1.70	5.10

[1] 50 gm. digested upon water bath for 2 hours with 50 c.c. concentrated HCl, filtered and washed with 500 c.c. water.

It is rather surprising to observe that even less decrease was effected in the case of Soil I by this drastic treatment than by the use of 2 c.c. of normal acid shown in Table XII. For the most part, however, the treatment shows greater effect than the previous one, indicating that a gradual solution of the soil constituents lowered the absorptive capacity.

As a means of changing soil structure, particularly that due to colloids, the agency of heat can be advantageously employed. Various other changes take place as well in the drying of soils, but it was thought that this procedure would give some indications worth while. Samples of all six soils were heated in a hot-air oven at 117° C. for 5 hours, after which they were treated with ammonia as usual. The effect of this treatment as recorded in Table XV shows a decrease in every case, the extent varying almost exactly in proportion to the water-holding capacities of the soils. The water-holding capacity is perhaps to some extent a function of the colloids in a soil and it is rather to be expected that the loss of water at high temperatures would destroy or incapacitate them in this

respect. The decreases shown appear to be due to this cause. The low decrease in the case of Soil II confirms the previous view that most of the absorption was due to CaO.

If the use of heat is still further employed to the extent of burning out the organic matter of the soils, other factors are surely eliminated. Portions of each soil were placed in iron crucibles and burned at redness for 30 minutes. Table XV gives the results obtained.

TABLE XV

EFFECT OF DRYING AND BURNING OF SOILS UPON THEIR ABSORPTION OF AMMONIA

Soil No.	No Treatment Ammonia Absorbed			Dried At 117° C. for 5 Hours Ammonia Absorbed				Organic Matter Burned Out at Red Heat Ammonia Absorbed			
	Lab. No.	Mg.	Av. Mg.	Lab. No.	Mg.	Av. Mg.	Increase Av. Mg.	Lab. No.	Mg.	Av. Mg.	Increase Av. Mg.
I	227	1.4	......	383	0.9	......	......	395	0.3	......	......
	228	1.4	1.4	384	0.9	0.90	—0.50	396	0.7	0.50	—0.90
II	229	13.9	......	385	7.1	......	......	397	11.6	......	......
	230	13.9	13.9	386	6.8	6.95	—6.95	398	12.6	12.10	—1.80
III	231	8.8	......	387	4.8	......	......	399	6.1	......	......
	232	9.2	9.0	388	3.4	4.10	—4.90	400	5.4	5.75	—3.25
IV	233	8.2	......	389	3.6	......	......	401	1.7	......	......
	234	7.8	8.0	390	3.2	3.40	—4.60	402	1.7	1.70	—6.30
V	235	10.5	......	391	2.7	......	......	403	2.7	......	......
	236	10.5	10.5	392	2.7	2.70	—7.80	404	2.0	2.35	—8.15
VI	237	6.5	......	393	1.7	......	......	405	2.5	......	......
	238	7.1	6.8	394	1.7	1.70	—5.10	406	2.5	2.50	—4.30

Practically every soil shows a large decrease due to this treatment except Soil I, where on account of its nature not much change would be expected. In the case of Soil II it will be remembered that it already had a large percentage of free CaO and the burning undoubtedly calcined more, so that a decrease in absorption took place. The destruction of the soil structure is perhaps responsible for the lowering of the absorption in the other cases. An interesting point to note is that in the cases of Soils I, IV and V the burning produced a smaller effect than merely drying. Inasmuch as the soil had first to pass through the drying stage before burning it must have been lowered as much as indicated by the former process. It was then necessary that some compensating action take place to restore the condition that effected the results obtained by burning. This might possibly be explained by assuming that there was some basicity produced by the burning. The loss of organic matter by burning appears to be of much less consequence than the loss of water.

This is confirmed in Table XVI, where the effects of the oxidation of the soil organic matter by nitric acid are shown. Fifty-gram portions of

the soils were digested for 2½ hours over a water bath with 100 c.c. of concentrated HNO_3. After filtering and washing with 1000 c.c. of distilled water the absorption was determined.

TABLE XVI

EFFECT OF OXIDATION OF ORGANIC MATTER BY NITRIC ACID UPON THE ABSORPTION OF AMMONIA BY SOILS

Soil No.	No Treatment			100 cc. Concentrated HNO_3			Decrease due to Treatment
	Lab. No.	Ammonia Absorbed		Lab. No.	Ammonia Absorbed		
		Mg.	Av. Mg.		Mg.	Av. Mg.	Av. Mg.
I	227	1.4	....	371	1.0	....	....
	228	1.4	1.4	372	1.0	1.00	0.40
II	229	13.9	....	373	13.3	....	....
	230	13.9	13.9	374	13.3	13.30	0.60
III	231	8.8	....	375	6.1	....	....
	232	9.2	9.0	376	6.1	6.10	2.90
IV	233	8.2	....	377	7.5	....	....
	234	7.8	8.0	378	7.1	7.30	0.70
V	235	10.5	....	379	7.1	....	....
	236	10.5	10.5	380	7.5	7.30	3.20
VI	237	6.5	....	381	4.4	....	....
	238	7.1	6.8	382	5.5	4.95	1.85

It is surprising to observe that there is so little effect from this treatment; the organic matter was not only destroyed but the acid-soluble salts were removed as well. Not as much change is noted in this case as with

TABLE XVII

EFFECT OF ORGANIC MATTER (COTTONSEED MEAL) UPON THE ABSORPTION OF AMMONIA BY SOILS

Soil No.	No Treatment			1 gm. Cottonseed Meal added to 50 gm. Soil			Decrease due to Treatment
	Lab. No.	Ammonia Absorbed		Lab. No.	Ammonia Absorbed		
		Mg.	Av. Mg.		Mg.	Av. Mg.	Av. Mg.
I	227	1.4	....	407	3.1	....	....
	228	1.4	1.4	408	3.1	3.10	1.70
II	229	13.9	....	409	13.9	....	....
	230	13.9	13.9	410	14.3	14.10	0.20
III	231	8.8	....	411	9.5	....	....
	232	9.2	9.0	412	9.2	9.35	0.35
IV	233	8.2	....	413	8.5	....	....
	234	7.8	8.0	414	8.5	8.50	0.50
V	235	10.5	....	415	10.7	....	....
	236	10.5	10.5	416	10.7	10.70	0.20
VI	237	6.5	....	417	7.5	....	....
	238	7.1	6.8	418	7.1	7.30	0.50

the treatment with the relatively weak (normal) HCl as reported in Table XIII. The only explanation at present seems to be that perhaps the use of 1000 c.c. of wash water more nearly washed out the acid than

the 500 c.c. used in the other instance. But even though the decrease is small the loss of the organic matter has a marked effect.

Increasing the organic matter by the use of cottonseed meal did not have a very great effect upon the absorption. This experiment was carried out by adding 1 gm. of the material to 50 gm. of soil, thoroughly mixing and treating with ammonia.

Although there was an increase in every case it was very small except with Soil I, which was lowest in organic matter. These increases are in all probability due principally to physical absorption.

TABLE XVIII

EFFECT OF CHLORIDE AND SULPHATE OF POTASSIUM UPON THE ABSORPTION OF AMMONIA BY SOILS

Soil No.	No Treatment Ammonia Absorbed			0.1 gm. K_2SO_4 Ammonia Absorbed				0.086 gm. KCl Ammonia Absorbed			
	Lab. No.	Mg.	Av. Mg.	Lab. No.	Mg.	Av. Mg.	Increase Av. Mg.	Lab. No.	Mg.	Av. Mg.	Increase Av. Mg.
I	227	1.4	......	431	1.0	......	......	443	1.7	......	......
	228	1.4	1.4	432	1.7	1.35	—0.05	444	1.7	1.70	0.30
II	229	13.9	......	433	12.6	......	......	445	11.9	......	......
	230	13.9	13.9	434	12.6	12.60	—1.30	446	11.2	11.55	—2.35
III	231	8.8	......	435	7.5	......	......	447	6.8	......	......
	232	9.2	9.0	436	6.7	7.10	—1.90	448	7.1	6.95	—2.05
IV	233	8.2	......	437	7.5	......	......	449	6.5	......	......
	234	7.8	8.0	438	6.8	7.15	—0.85	450	6.5	6.50	—1.50
V	235	10.5	......	439	9.2	......	......	451	8.2	......	......
	236	10.5	10.5	440	9.2	9.20	—1.30	452	8.2	8.20	—2.30
VI	237	6.5	......	441	5.6	......	......	453	5.1	......	......
	238	7.1	6.8	442	5.3	5.45	—1.35	454	5.1	5.10	—1.70

From the practical standpoint the methods of controlling the absorptive properties of soils are rather limited. The addition of lime, alteration of physical condition, application of organic matter and fertilizer salts constitute nearly all of the means available for the purpose. To determine the effect of the addition of potash and phosphoric acid upon the absorption of ammonia, experiments were carried out as follows: four separate sets (50-gm. portions) of soils were treated respectively with 0.1 gm. K_2SO_4; 0.086 gm. KCl (equivalent K_2O); 0.2 gm. acid phosphate; and 0.1 gm. K_2SO_4 and 0.2 gm. acid phosphate together. The results are given in Tables XVIII and XIX.

With only one exception, and that almost within experimental error, the use of potash[1] in either form caused a decrease in the absorption of ammonia. The decrease was, however, more marked in the case of the muriate. This is perhaps to be expected, inasmuch as this salt is more

[1] See figure 1.

strongly absorbed by the soil than the sulfate. Both of these observations confirm similar ones made upon other soils.

Table XIX shows that in practically every case the use of acid phosphate tends to decrease slightly the soil's absorptive power for ammonia. However, a combination of acid phosphate and K_2SO_4 caused a considerable decrease in the absorption. This decrease was greater than the combined effect of the two substances acting alone.

The fact that potassium can replace ammonium and that the acid phosphate is acidic in character, are probably the causes of the lowering of the absorptive power.

TABLE XIX

EFFECT OF ACID PHOSPHATE ALONE AND WITH POTASH UPON THE ABSORPTION OF AMMONIA BY SOILS

Soil No.	No Treatment Ammonia Absorbed			0.2 gm. Acid Phosphate Ammonia Absorbed				0.1 gm. K_2SO_4 + 0.2 gm. A. P. Ammonia Absorbed			
	Lab. No.	Mg.	Av. Mg.	Lab. No.	Mg.	Av. Mg.	Increase Av. Mg.	Lab. No.	Mg.	Av. Mg.	Increase Av. Mg.
I	227	1.4	......	455	1.7	......	......	467	0.7	......	......
	228	1.4	1.4	456	1.7	1.70	0.30	468	1.0	0.85	—0.55
II	229	13.9	......	457	13.9	......	......	469	10.2	......	......
	230	13.9	13.9	458	13.6	13.75	—0.15	470	10.2	10.20	—3.70
III	231	8.8	......	459	8.8	......	......	471	5.8	......	......
	232	9.2	9.0	460	9.0	8.90	—0.10	472	5.8	5.80	—3.20
IV	233	8.2	......	461	7.5	......	......	473	4.8	......	......
	234	7.8	8.0	462	7.5	7.50	—0.50	474	4.8	4.80	—3.20
V	235	10.5	......	463	9.9	......	......	475	6.6	......	......
	236	10.5	10.5	464	9.9	9.90	—0.60	476	7.1	6.85	—3.65
VI	237	6.5	......	465	5.8	......	......	477	3.1	......	......
	238	7.1	6.8	466	5.8	5.80	—1.00	478	3.6	3.35	—3.45

Briefly reviewing the work in Part I, we find ourselves still further impressed with the complexity of the absorption phenomenon. In a simple way relationships were pointed out which indicated that the lime (CaO) content could be a strong factor in the absorption; that the contents of iron, alumina, magnesia, carbon dioxide, and organic matter, as well as mechanical composition, were undoubtedly correlated to some extent. That a large percentage of the absorption may be traced to the colloids and the finer soil particles seems clear. The soil organic matter, soluble matter and reaction are elements to be considered. The presence of KCl, K_2SO_4, or acid phosphate, decreases the soil's capacity for ammonia.

The phenomenon of absorption appears to be a complex of numerous factors of physical, physical-chemical, chemical, and perhaps biological nature, all of which react in one direction or another, depending upon the conditions of their balance.

Part II

Factors Affecting the Vertical Distribution of Ammonia Applied to Soils

The vertical distribution of applied ammonia must bear some relation to its effectiveness. That this distribution is in a certain measure a function of the fixing or absorptive power of a soil is very probable. It appears, then, that by combining the study both of absorption and distribution of ammonia some more or less valuable information might be obtained.

Huston's statement that the absorption of a soil to a depth of 9 inches was more than 32 times as great as it would be called upon to exert in fixing a dressing of 500 pounds of ammonium sulfate would indicate that even the rather large application of 500 pounds could be fixed in a little more than a quarter of an inch of soil. Of course this would assume a perfectly even lateral distribution which could never be obtained. But even if the distribution were not made carefully the indication is that we might expect all of it to be fixed within the first inch. It will be remembered that of the soils used in this work the one with the highest fixing power was able to fix only about 2700 pounds of ammonium sulfate, and the one with the lowest, scarcely a tenth as much per acre 6 2/3 inches. Evidently the soils with which Huston worked had absorptive capacities far in excess of those possessed by the soils of New Jersey, even though many of these soils are exceptionally fertile. The problem of the distribution of applied ammonia is therefore a more practical one for New Jersey conditions.

Crawley and Duncan (6) have shown that in certain Hawaiian soils nearly one-half of the applied ammonia was fixed in the first two inches, nearly four-fifths in the first three inches, and nearly all in the first four inches.

But broad statements regarding the depth of fixation of ammonia in soils are undoubtedly misleading and of a little value; the individual conditions will make the problem a different one in every case. The work of which the following is a report does not warrant generalizations, but merely shows the range of results obtained and the effect of a few practical factors which can easily be controlled.

The work was carried out upon soils contained in paraffined paper tubes, having an inside diameter of 1¾ inches and a length of 8 inches. The tubes were closed at one end with paraffined corks and the soil column was approximately 6 2/3 inches in height. The weights of the respective soils were as follows:

Soil No. I	Soil No. II	Soil No. III	Soil No. IV	Soil No. V	Soil No. VI
Norfolk Sand	Collington Sandy Loam	Sassafras Loam	Dutchess Silt Loam	Penn Loam	Alloway Clay
380 gm.	335 gm.	295 gm.	290 gm.	275 gm.	325 gm.

The ammonia was added to the surface of the soils in the tubes in 5 c.c. of a N/2 solution of ammonium sulfate (42.5 mg. NH_3), and water added to bring them to the desired moisture content.

In order to get the ammonia fixed or present at different depths, the tube was placed in an improvised miter box and cut into sections. The soil sections, as well as the cardboard rings, were then placed in copper distillation flasks and the ammonia distilled off by the use of magnesium oxide. All determinations were made in duplicate from which the corresponding blanks were subtracted.

That the vertical distribution would change somewhat with the time allowed for standing seemed quite probable and it therefore appeared necessary to run a preliminary test to determine a satisfactory period. For this test Soil IV, the Dutchess silt loam, was chosen because it represented a fairly heavy soil in which it was thought that movement of salts would be relatively slow. To three pairs of tubes containing this soil, ammonia and water were added. One pair was sectioned, and the ammonia determined on each of three consecutive days. The results recorded in Table XX show that the time element beyond the first day is

TABLE XX

EFFECT OF TIME UPON THE VERTICAL DISTRIBUTION OF AMMONIA[1]

No. Soil	Inches Depth	1 Day		2 Days		3 Days	
		Lab. No.	Ammonia Mg.	Lab. No.	Ammonia Mg.	Lab.	Ammonia Mg.
IV	0-1	483	13.9	489	12.9	495	13.0
	1-2	484	8.8	490	9.6	496	9.3
	2-3	485	8.0	491	8.0	497	7.5
	3-4	486	8.5	492	7.2	498	8.0
	4-5	487	2.4	493	3.1	499	3.7
	5-6 2/3	488	1.5	494	1.8	500	1.9

[1] Blanks not deducted.

not a very potent element in affecting the distribution of ammonia. However, the choice of the second day as the best length of time seemed warranted inasmuch as there was less change between the second and third days than between the first and second.

It was at first planned to leach the soils in the tubes and then note the position of the fixed ammonia, but after finding that the time necessary to do so was so variable with the soil, the idea was given up. To approximate, after a manner, the leaching effect of rain, it was decided to add the ammonia as before and then bring the soil to the desired moisture content by pouring the water in on top of the ammonia. The quantity of water to use was next studied. Three soils, Nos. I, III and V were used, representing the lightest, medium and heaviest. In one set of tubes the moisture content was brought to 50 per cent, in the next to 75 per cent,

and in the third to 100 per cent of the water-holding capacity. After standing for two days the tubes were sectioned and the ammonia determined as before. In Table XXI we see that the increased moisture has the effect that we might expect. By glancing at figure 4 we can see perhaps a little more clearly that the lower moisture content favors a larger amount of ammonia in the surface layers. A moisture content of 50 per cent of the water-holding capacity was chosen for the subsequent work.

The wide variation in the vertical distribution of ammonia as shown in Table XXII is most interesting. Starting with Soil I, the lightest one,

TABLE XXI

EFFECT OF DIFFERENT MOISTURE CONTENTS OF SOILS UPON THE VERTICAL
DISTRIBUTION OF AMMONIA[1] AT 2 DAYS

Soil No.	Depth Inches	50% Water-Holding Capacity		75% Water-Holding Capacity		100% Water-Holding Capacity	
		Lab. No.	Ammonia Mg.	Lab. No.	Ammonia Mg.	Lab. No.	Ammonia Mg.
I	0-1	501	2.0	516	1.9	531	1.0
	1-2	502	1.9	517	1.4	532	1.4
	2-3	503	4.4	518	1.7	533	1.5
	3-4	504	10.9	519	3.2	534	4.4
	4-6 2/3	505	25.2	520	31.4	535	32.8
III	0-1	506	15.1	521	12.9	536	10.7
	1-2	507	10.9	522	10.9	537	8.5
	2-3	508	8.8	523	7.0	538	7.1
	3-4	509	5.8	524	5.6	439	6.6
	4-6 2/3	510	0.0	525	1.5	540	3.6
V	0-1	511	16.5	526	17.0	541	15.1
	1-2	512	11.9	527	11.9	542	10.0
	2-3	513	10.7	528	10.0	543	7.7
	3-4	514	2.5	529	4.4	544	8.3
	4-6 2/3	515	0.3	530	1.5	545	4.4

[1] Blanks not deducted.

we find very little ammonia fixed in the upper few inches. The first and second inches have about the same, then there is a gradual increase in proportion to the depth. This curve in figure 5 is probably distorted from the natural one owing to the fact that the tube was so short. If the column of soil had been a foot or more in length it is reasonable to believe that approximately the same amount, 1.7 mg. of ammonia, would have been fixed per inch of depth; the reason that there is more ammonia present per inch in the lower layers is no doubt because it could not distribute itself at a greater depth.

In contrast to the behavior of Soil I, Soil II shows a strikingly large fixation of ammonia in the surface inch, almost two-thirds of the total amount applied being held there. Beyond the third inch in depth there is practically no further fixation. Since this soil is not heavy it perhaps is
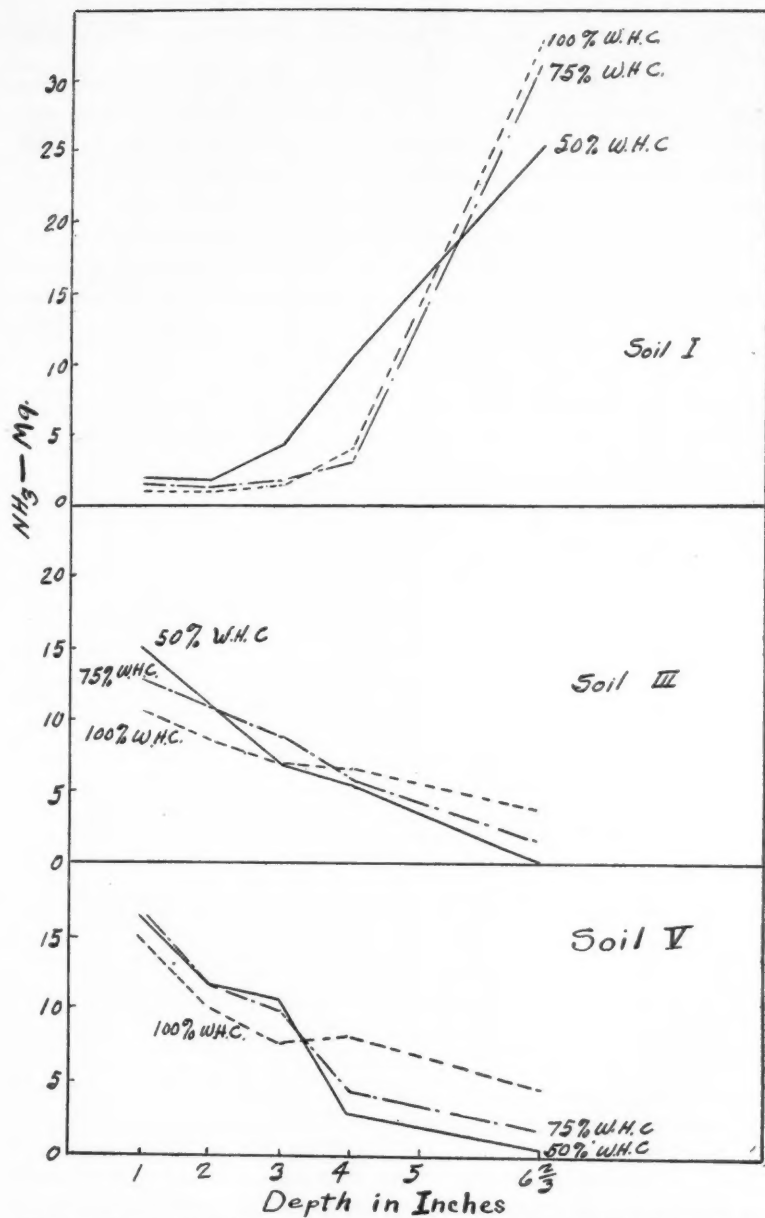
Fig. 4.—Diagram showing the effect of moisture upon the vertical distribution of ammonia.

surprising that the fixing power is so great; however, it correlates very well with the behavior manifested in Part I.

With Soils III, IV, V, and VI we have practically the same conditions shown. Three of these soils show a maximum fixation in the first inch, and the larger amount in the second inch of Soil VI is very small. With this exception a gradual decrease with depth is observed in every case.

TABLE XXII

VERTICAL DISTRIBUTION OF AMMONIA

Soil No.	Lab. No.	Depth Inches	Ammonia		Soil No.	Lab. No.	Ammonia	
			Mg.	Av.Mg			Mg.	Av. Mg.
I	547	0-1	2.0	....	IV	583	11.4	....
	548	...	1.4	1.70		584	10.4	10.90
	549	1-2	2.0	....		585	8.2	....
	550	...	1.4	1.70		586	10.4	9.30
	551	2-3	3.4	....		587	8.3	....
	552	...	2.0	2.70		588	7.7	8.00
	553	3-4	5.1	....		589	5.8	....
	554	...	3.9	4.50		590	4.4	5.10
	555	4-5	10.1	....		591	2.5	....
	556	...	12.5	11.30		592	1.9	2.20
	557	5-6 2/3	18.1	....		593	0.9	....
	558	...	18.7	18.40		594	0.5	0.70
II	559	0-1	26.4	....	V	595	16.0	....
	560	...	30.4	28.40		596	16.8	16.40
	561	1-2	11.9	....		597	12.6	.. ..
	562	...	10.9	11.40		598	13.2	12.90
	563	2-3	4.9	....		599	6.6	....
	564	...	1.7	3.30		600	8.4	7.50
	565	3-4	0.9	....		601	1.5	....
	566	...	0.9	0.90		602	1.2	1.35
	567	4-5	0.5	....		603	0.5	....
	568	...	0.3	0.40		604	0.5	0.50
	569	5-6 2/3	—0.2	....		605	0.2	....
	570	...	—0.3	—0.25		606	0.2	0.20
III	571	0-1	15.1	....	VI	607	11.9	....
	572	...	13.8	14.45		608	9.2	10.55
	573	1-2	10.9	....		609	7.6	....
	574	...	10.7	10.80		610	13.8	10.70
	575	2-3	8.8	....		611	8.5	....
	576	...	8.4	8.60		612	5.8	7.15
	577	3-4	4.8	....		613	5.8	....
	578	...	5.3	5.05		614	6.3	6.05
	579	4-5	1.4	....		615	2.0	....
	580	...	1.9	1.65		616	5.1	3.55
	581	5-6 2/3	—0.3	....		617	1.3	....
	582	...	—0.2	—0.25		618	1.2	1.25

If we arrange the soils in Table XXII in the order of the amount of ammonia held in the first inch we have them in the following order: II, V, III, IV, VI, I, which it is interesting to note, corresponds exactly with their relative absorptive power for ammonia. We are without doubt warranted in believing that the greater a soil's absorptive capacity for ammonia, the nearer to the surface will the applied ammonia be fixed. And since the nearer the surface that the ammonia remains the less is the

likelihood of loss, it perhaps is of some importance not to lose sight of at least one method of increasing the absorptive power of the soil.

As indicated in Table X, the use of CaO considerably increased the absorptive powers of all soils but one, which already had an excess of it. We would expect therefore, that the addition of lime to all soils but No. II, would effect a greater surface retention than is manifest in the untreated soils. Five-tenths-gram portions of CaO were accordingly weighed out, applied to the tubes containing the soils, and with a spatula mixed with the surface two inches of soil. Ammonia was added as before with moisture, and determined in the different sections after standing for two days.
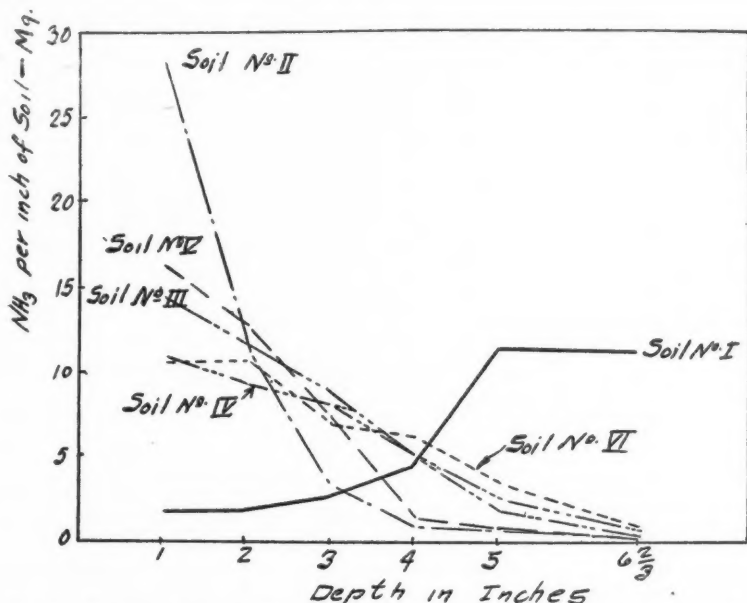
Fig. 5.—Diagram showing the vertical distribution of ammonia applied to soils.

In Table XXIII the effect of this treatment is fully brought out. In every instance but that of No. IV there is a decrease in the fixing power of the surface inch. At first this seems to be rather contrary to the effect which we would expect from Table X; however, if we pass to Table XI we can readily supply an explanation. The addition of 0.5 gm. CaO was apparently enough to produce a large excess in all but Soil IV. It will be remembered that this soil possessed the highest lime requirement and that in Table XI no appreciable depression was produced up to above 0.3 gm.

per 50 gm. of soil. And since there was undoubtedly an excess in all the rest of the soils the lowering of the absorptive power is not strange. But in the second inch it is possible that not so much lime was present and the absorptive power was raised in every case. In the third inch there was with Soils I, II and VI an increase due to CaO, but a decrease with the

TABLE XXIII

EFFECT OF CaO UPON THE VERTICAL DISTRIBUTION OF AMMONIA

Soil	Lab	Depth Inches	0.5 gm. CaO Ammonia		Check Table XXII Av. Mg.	Increase due to CaO Av. Mg.	Soil No.	Lab. No.	0.5 gm. CaO Ammonia		Check Table XXII Av. Mg.	Increase due to Treatment. Av. Mg.
			Mg.	Av. Mg.					Mg.	Av. Mg.		
I	619	0-1	0.5	....	....	....	IV	655	13.9	....	....	....
	620	...	1.2	0.85	1.70	—0.85		656	13.4	13.65	10.90	2.75
	621	1-2	2.7	....	....	....		657	14.8	....	....	....
	622	...	2.6	2.65	1.70	0.95		658	11.5	13.15	9.30	3.85
	623	2-3	11.5	....	....	....		659	6.3	....	....	....
	624	...	8.8	10.15	2.70	7.45		660	3.4	4.85	8.00	—3.15
	625	3-4	11.0	....	....	....		661	1.7	....	....	....
	626	...	6.6	8.80	4.50	4.30		662	3.7	2.70	5.10	—2.40
	627	4-5	7.3	....	....	....		663	0.7	....	....	....
	628	...	8.3	6.95	11.30	—4.35		664	1.7	1.20	2.20	—1.00
	629	5-6 2/3	4.8	....	....	....		665	0.3	....	....	....
	630	...	11.7	8.25	18.40	—10.15		666	—0.2	0.05	0.70	—0.65
II	631	0-1	3.7	....	....	....	V	667	12.7	....	....	....
	632	...	4.3	4.00	28.40	—24.40		668	12.2	12.45	16.40	—3.95
	633	1-2	16.8	....	....	....		669	21.6	....	....	....
	634	...	17.4	17.10	11.40	5.70		670	20.2	20.90	12.90	8.00
	635	2-3	17.5	....	....	....		671	5.1	....	....	....
	636	...	18.2	17.85	3.30	14.55		672	6.8	5.95	7.50	—1.55
	637	3-4	2.4	....	....	....		673	1.0	....	....	....
	638	...	0.9	1.65	0.90	0.75		674	1.0	1.00	1.35	—0.35
	639	4-5	1.0	....	....	....		675	0.9	....	....	....
	640	...	0.2	0.60	0.40	0.20		676	0.3	0.60	0.50	0.10
	641	5-6.2/3	0.3	....	....	....		677	0.5	....	....	....
	642	...	—0.3	0.00	—0.25	—0.25		678	0.0	0.25	0.20	0.05
III	643	0-1	8.3	....	....	....	VI	679	5.1	....	....	....
	644	...	7.6	13.40	14.45	—1.05		680	2.7	3.90	10.55	—6.65
	645	1-2	19.2	....	....	....		681	12.4	....	....	....
	646	...	17.9	18.55	10.80	7.75		682	19.0	15.70	10.70	5.00
	647	2-3	7.1	....	....	....		683	13.8	....	....	....
	648	...	7.1	7.10	8.60	—1.50		684	9.5	11.65	7.15	4.50
	649	3-4	2.9	....	....	....		685	3.6	....	....	....
	650	...	4.9	3.90	5.05	—1.15		686	3.4	3.50	6.05	—2.55
	651	4-5	0.3	....	....	....		687	0.9	....	....	....
	652	...	0.2	0.25	1.65	—1.40		688	0.2	0.55	3.55	—3.00
	653	5-6 2/3	—0.3	....	....	....		689	0.0	....	....	....
	654	...	0.0	—0.15	—0.25	—0.40		690	—0.2	—0.10	1.25	—1.35

rest. Wherever a decrease was observed at this depth it is to be noted that there was a very large fixation in the upper two inches. There would be a very small amount of ammonia left to get down to the deeper layers and we would expect just the conditions shown. A point of interest is that of Soil II. The first inch held relatively little ammonia and the sec-

ond, probably containing a little less CaO, held considerably more. At the third inch where the absorptive capacity of the soil was not impaired by the lime we get practically all the rest of the ammonia.

TABLE XXIV

EFFECT OF $CaCO_3$ UPON THE VERTICAL DISTRIBUTION OF AMMONIA

Soil No.	Lab. No.	Depth Inches	1 gm. $CaCO_3$ Ammonia Mg.	Av. Mg.	Check Table XXII Av. Mg.	Increase due to $CaCO_3$ Av. Mg.	Soil No.	Lab. No.	1 gm. $CaCO_3$ Ammonia Mg.	Av. Mg	Check Table XXII Av. Mg.	Increase due to $CaCO_3$ Av. Mg.
I	691	0-1	2.7	....	....	....	IV	727	10.2	....	....	....
	692	...	2.0	2.35	1.70	0.65		728	9.9	10.05	10.90	—0.85
	693	1-2	3.2	....	....	....		729	9.2	....	....	....
	694	...	3.6	3.40	1.70	1.70		730	9.2	9.20	9.30	—0.10
	695	2-3	2.4	....	....	....		731	6.6	....	....	....
	696	...	2.9	2.65	2.70	—0.05		732	5.1	5.85	8.00	—2.15
	697	3-4	3.2	....	....	....		733	6.8	....	....	....
	698	...	4.9	4.05	4.50	—0.45		734	6.5	6.65	5.10	1.55
	699	4-5	8.5	....	....	....		735	3.1	....	....	....
	700	...	9.9	9.20	11.30	—2.10		736	4.3	3.70	2.20	1.50
	701	5-6 2/3	21.2	....	....	....		737	—0.2	....	....	....
	702	...	17.7	19.45	18.40	1.05		738	—0.3	—0.25	0.70	—0.95
II	703	0-1	25.5	....	....	....	V	739	15.6	....	....	....
	704	...	25.5	25.50	28.40	—2.90		740	15.6	15.60	16.4	—0.80
	705	1-2	12.4	....	....	....		741	13.6	....	....	....
	706	...	13.8	13.10	11.40	1.70		742	13.8	13.70	12.90	0.80
	707	2-3	3.2	....	....	....		743	9.7	....	....	....
	708	...	2.0	2.60	3.30	—0.70		744	8.8	9.25	7.50	1.75
	709	3-4	0.3	....	....	....		745	3.1	....	....	....
	710	...	0.3	0.30	0.90	—0.60		746	2.9	3.00	1.35	1.65
	711	4-5	0.5	....	....	....		747	0.0	....	....	....
	712	...	0.3	0.40	0.40	0.00		748	0.5	0.25	0.50	—0.25
	713	5-6 2/3	0.3	....	....	....		749	—0.5	....	....	....
	714	...	0.0	0.15	—0.25	0.40		750	0.3	—0.10	0.20	—0.30
III	715	0-1	11.7	....	....	....	VI	751	10.0	....	....	....
	716	...	11.2	11.45	14.45	—3.00		752	7.7	8.85	10.55	—1.70
	717	1-2	10.7	....	....	....		753	9.2	....	....	....
	718	...	10.9	10.80	10.80	0.00		754	8.5	8.85	10.70	—1.85
	719	2-3	8.0	....	....	....		755	5.3	....	....	....
	720	...	6.8	7.40	8.60	—1.20		756	4.3	4.80	7.15	—2.35
	721	3-4	7.3	....	....	....		757	8.0	....	....	....
	722	...	7.7	7.50	5.05	2.45		758	8.7	8.35	6.05	2.30
	723	4-5	1.7	....	....	....		759	3.7	....	....	....
	724	...	3.2	2.45	1.65	0.80		760	5.8	4.75	3.55	1.20
	725	5-6 2/3	0.0	....	....	....		761	0.2	....	....	....
	726	...	0.3	0.15	—0.25	0.40		762	0.2	0.20	1.25	—1.45

It will be noted throughout that the tendency of the lime is to locate most of the ammonia in the second and third inches of the soil where we perhaps have the most efficient bacterial activities. In practically every case a larger amount of ammonia is held in the first three inches in the limed than in the unlimed soils.

That the effect of $CaCO_3$ upon the vertical distribution is of no great importance is shown in Table XXIV. If anything the tendency is toward lowering slightly the position of the ammonia. Why this should be true seems inexplicable with the data at hand.

TABLE XXV

EFFECT OF K_2SO_4 UPON THE VERTICAL DISTRIBUTION OF AMMONIA

Soil No.	Lab. No.	Depth Inches	0.25 gm. K_2SO_4 Ammonia Mg.	Av. Mg.	Check Table XXII Av. Mg.	Increase due to K_2SO_4 Av. Mg.	Soil No.	Lab. No.	0.25 gm. K_2SO_4 Ammonia Mg.	Av. Mg.	Check Table XXII Av. Mg.	Increase due to K_2SO_4 Av. Mg.
I	763	0-1	1.9	....	....	....	IV	799	11.4	....	....	....
	764	...	1.4	1.65	1.70	—0.05		800	7.3	9.35	10.90	—1.55
	765	1-2	1.5	....	....	....		801	6.5	....	....	....
	766	...	1.5	1.50	1.70	—0.20		802	8.2	7.35	9.30	—1.95
	767	2-3	1.9	....	....	....		803	7.1	....	....	....
	768	...	1.5	1.70	2.70	—1.00		804	6.1	6.60	8.00	—1.40
	769	3-4	3.1	....	....	....		805	9.0	....	....	....
	770	...	2.4	2.75	4.50	—1.75		806	7.7	8.35	5.10	3.25
	771	4-5	8.3	....	....	....		807	1.5	....	....	....
	772	...	7.0	7.65	11.30	—3.65		808	8.5	5.00	2.20	2.80
	773	5-6 2/3	24.8	....	....	....		809	3.4	....	....	....
	774	...	26.7	25.75	18.40	7.35		810	3.6	3.50	0.70	2.80
II	775	0-1	24.8	....	....	....	V	811	14.6	....	....	....
	776	...	21.2	23.00	28.40	—5.40		812	14.0	14.30	16.40	—2.10
	777	1-2	12.7	....	....	....		813	12.1	....	....	....
	778	...	14.5	13.60	11.40	2.20		814	11.6	11.85	12.90	—1.05
	779	2-3	4.3	....	....	....		815	10.4	....	....	....
	780	...	5.4	4 .85	3.30	1.55		816	12.4	11.40	7.50	3.90
	781	3-4	1.4	....	....	....		817	4.9	....	....	....
	782	...	1.0	1.20	0.90	0.30		818	7.0	5.95	1.35	4.60
	783	4-5	0.3	....	....	....		819	0.3	....	....	....
	784	...	0.2	0.25	0.40	—0.15		820	1.2	0.75	0.50	0.25
	785	5-6 2/3	0.3	....	....	....		821	0.5	....	....	....
	786	...	0.0	0.15	—0.25	0.40		822	0.2	0.35	0.20	0.15
III	787	0-1	14.3	....	....	....	VI	823	9.7	....	....	....
	788	...	10.9	12.60	14.45	—1.85		824	8.8	9.25	10.55	—1.30
	789	1-2	7.2	....	....	....		825	6.6	....	....	....
	790	...	8.5	8.85	10.80	—1.95		826	6.1	6.35	10.70	—4.35
	791	2-3	6.6	....	....	....		827	6.8	....	....	....
	792	...	7.3	6.95	8.60	—1.65		829	6.3	6.55	7.15	—0.50
	793	3-4	8.2	....	....	....		829	6.3	....	....	....
	794	...	7.1	7.65	5.05	2.60		830	8.2	7.25	6.05	1.20
	795	4-5	6.5	....	....	....		831	8.0	....	....	....
	796	...	6.5	6.50	1.65	4.85		832	6.1	7.05	3.55	3.50
	797	5-6 2/3	0.5	....	....	....		833	2.7	....	....	....
	798	...	1.9	1.20	—0.25	1.45		834	2.4	2.55	1.25	1.30

When ammonium sulfate is applied to soils with either sulfate of potash or acid phosphate a modification of the distribution will be effected. In order to study these modifications 0.25-gm. portions of K_2SO_4 were added to one set of soils in tubes, and 0.25-gm. portions of acid phosphate to another. The effect of these two materials upon the distribution of

ammonia was determined and recorded in Tables XXV and XXVI.

Since potassium is able to replace ammonium it would appear that the effect of adding it would be to lower the absorption of ammonia in the surface layers of the soil. A study of the table shows this to be exactly

TABLE XXVI

EFFECT OF ACID PHOSPHATE UPON THE VERTICAL DISTRIBUTION OF AMMONIA

Soil No.	Lab. No.	Depth Inches	0.25 gm. Acid Phos. Ammonia		Check Table XXII Av. Mg.	Increase due to A. P. Av. Mg.	Soil No.	Lab. No.	0.25 gm. Acid Phos. Ammonia		Check Table XXII Av. Mg.	Increase due to A. P. Av. Mg.
			Mg.	Av. Mg.					Mg.	Av. Mg.		
I	835	0-1	1.9	....	....	....	IV	871	8.0	....	....	....
	836	...	0.7	1.30	1.70	—0.40		872	5.4	6.70	10.90	—4.20
	837	1-2	1.9	....	....	....		873	6.8	....	....	....
	838	...	1.4	1.65	1.70	—0.05		874	6.5	6.65	9.30	—2.65
	839	2-3	2.0	....	....	....		875	6.1	....	....	....
	840	...	2.4	2.20	2.70	—0.50		876	7.8	6.95	8.00	—1.05
	841	3-4	3.1	....	....	....		877	9.3	....	....	....
	842	...	5.5	4.30	4.50	—0.20		878	8.3	8.80	5.10	3.70
	843	4-5	7.8	....	....	....		879	8.5	....	....	....
	844	...	10.5	9.15	11.30	—2.15		880	4.8	6.65	2.20	4.45
	845	5-6 2/3	25.2	....	....	....		881	1.7	....	....	....
	846	...	18.9	22.05	18.40	3.65		882	—0.2	0.75	0.70	0.05
II	847	0-1	21.6	....	....	....	V	883	12.7	....	....	....
	848	...	24.5	23.05	28.40	—5.35		884	12.2	12.45	16.40	—3.95
	849	1-2	12.9	....	....	....		885	9.0	....	....	....
	850	...	13.4	13.15	11.40	1.75		886	13.4	11.20	12.90	—1.70
	851	2-3	5.1	....	....	....		887	10.4	....	....	....
	852	...	4.3	4.70	3.30	1.40		888	10.9	10.65	7.50	3.15
	853	3-4	1.2	....	....	....		889	9.0	....	....	....
	854	...	—0.2	0.50	0.90	—0.40		890	3.1	6.05	1.35	4.70
	855	4-5	0.7	....	....	....		891	2.2	....	....	....
	856	...	0.3	0.50	0.40	0.10		892	0.3	1.25	0.50	0.75
	857	5-6 2/3	0.9	....	.. ..	....		893	0.5	....	....	....
	858	...	0.0	0.45	—0.25	0.70		894	0.0	0.25	0.20	0.05
III	859	0-1	12.7	....	....	....	VI	895	9.4	....	....	....
	860	...	9.0	10.85	14.45	—3.60		896	5.1	7.25	10.55	—3.30
	861	1-2	7.3	....	....	....		897	6.3	....	....	....
	862	...	10.7	9.00	10.80	—1.80		898	5.4	5.85	10.70	—4.85
	863	2-3	5.8	....	....	....		899	7.0	....	....	....
	864	...	10.2	8.00	8.60	—0.60		900	8.7	7.85	7.15	0.70
	865	3-4	8.3	....	....	....		901	7.0	....	....	....
	866	...	8.0	8.15	5.05	3.10		902	10.4	8.70	6.05	2.65
	867	4-5	6.6	....	....	....		903	7.7	....	....	....
	868	...	0.7	3.65	1.65	2.00		904	4.4	6.05	3.55	2.50
	869	5-6 2/3	0.5	....	....	....		905	2.6	....	....	....
	870	...	—0.3	0.10	—0.25	0.35		906	—0.5	1.05	1.25	—0.20

the case. There is an increase in the amount of ammonia in the lower layers at the expense of the surface layers. It is doubtful if this would have any practical significance in any but the lightest soils where the danger of loss by leaching is at a maximum.

(ii—24)
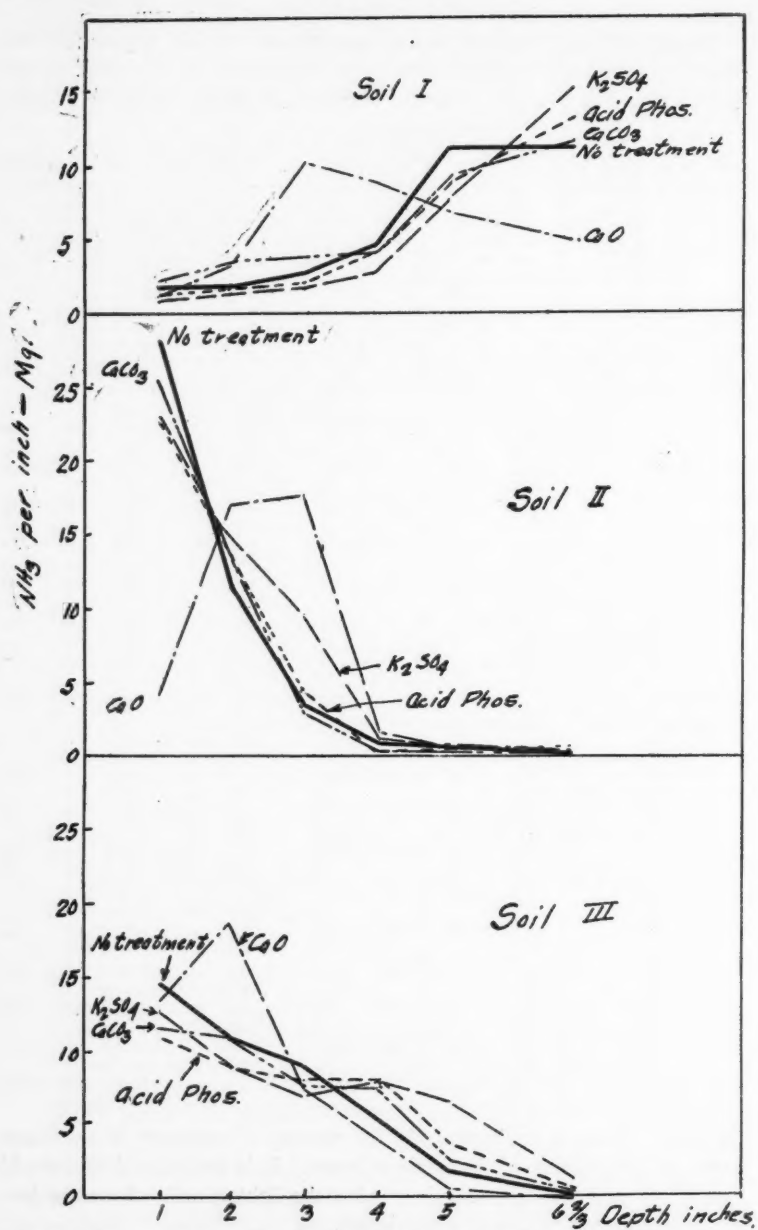
Fig. 6.—Diagram showing the effect of CaO, CaO₃, K₂SO₄ and acid phosphate upon the vertical distribution of applied ammonia (Soils I, II and III).
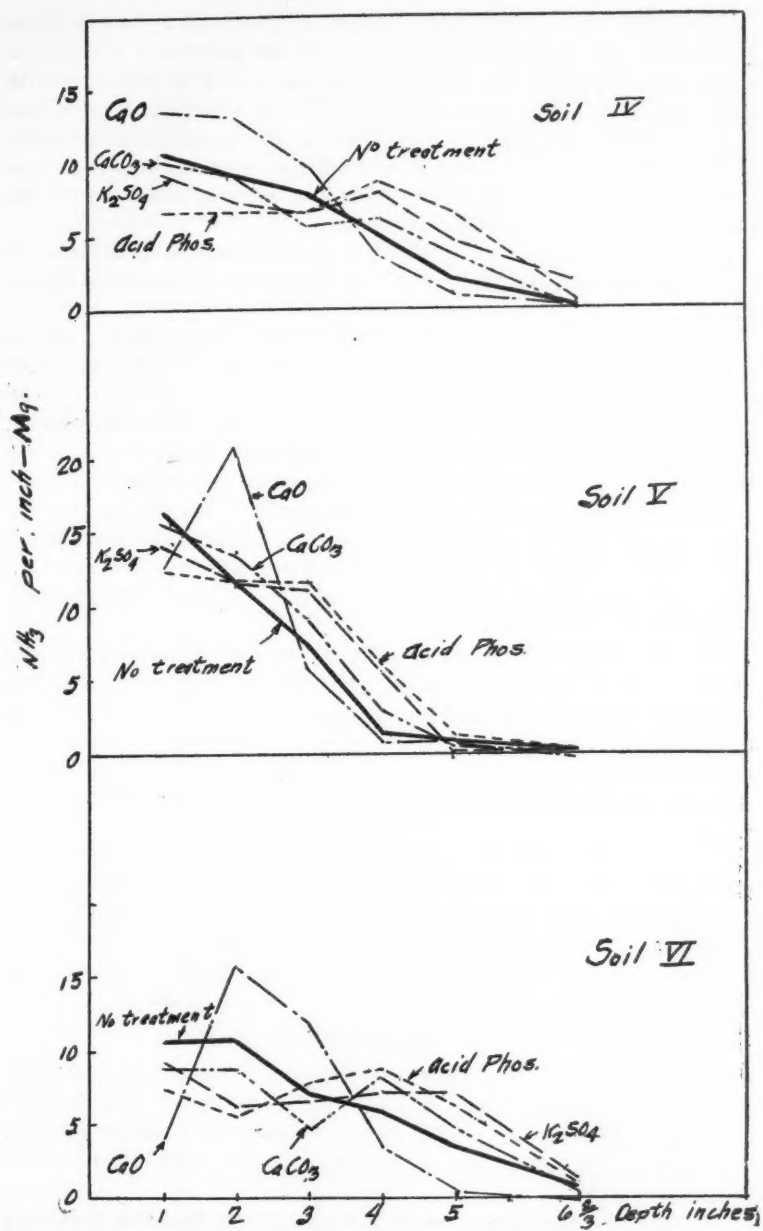
Fig. 7.—Diagram showing the effect of CaO, CaCO₃, K₂SO₄ and acid phosphate upon the vertical distribution of applied ammonia (Soils IV, V and VI).

The effect of acid phosphate as seen in Table XXVI seems to be greater than that of potash per unit applied, and since there is usually a much larger amount of the former applied per acre it is possible that its effect may reach significant proportions. The use of both acid phosphate and potash with ammonia may have their action magnified as indicated by Table XIX. Even if there were no danger of direct loss from this cause it would undoubtedly have a deleterious influence in most cases due to the lowering of the absorbed ammonia.

The effects of CaO, $CaCO_3$, K_2SO_4 and acid phosphate upon the vertical distribution of applied ammonia are graphically represented in figures 6 and 7.

It appears evident that the distribution of ammonia applied to soils is a variable having wide limits depending largely upon the physical nature of the soils but also appreciably upon their chemical constitution. The presence of lime up to a certain point will enhance the proper distribution and in a practical way will undoubtedly tend toward conserving the nitrogen applied. Acid phosphate and potash exert an influence which might not be considered beneficial to the best distribution. It is, however, probable that the effect of these elements in other ways, principally biologically, serves to more than compensate for this, and makes their resultant effect decidedly advantageous in the utilization of nitrogen from ammonium sulfate.

To give to the results a practical interpretation requires considerable caution. In the absence of much experimental data concerning the method of application of sulfate of ammonia, it is perhaps necessary to apply the results obtained in a more or less flexible way. Nevertheless, certain points were brought out in regard to the distribution of the applied ammonia which will undoubtedly help in our understanding of the problems involved.

The indications therefrom are that ammonium sulfate should be applied much shallower in light than in heavy soils, particularly if the soils are acid. The presence of burnt lime is preferable to ground limestone if the danger of loss of nitrogen by leaching is to be considered. The use of potash and acid phosphate would argue for a shallower application of ammonia.

SUMMARY

1. New Jersey soils present wide ranges of absorptive capacity for ammonia; the smallest amount was observed in the lightest soil, the Norfolk sand, corresponding to 266 pounds of ammonium sulfate per acre 6 2/3 inches; the largest amount in the Collington sandy loam of 2642 pounds per acre.

2. That the absorption process is a very complicated one, depending upon many factors and not the result of any one or two, appears to be

beyond doubt. For any one factor, the presence of CaO seems to exert more influence than any other. In general, mechanical and chemical composition, hygroscopy, etc., all undoubtedly have some effect; to a certain extent, the absorption of ammonia follows the percentage of combined iron and alumina, calcium oxide and carbon dioxide, as well as organic matter and physical properties of the soil. The presence of colloids, and conditions which favor them increase the absorptive power of the soil. Soils owe their property of absorption of ammonia to chemical and physical factors, and perhaps others.

3. The presence of potash or acid phosphate, either alone or in combination, reduces the absorptive capacity of the soil.

4. The distribution of applied ammonia in soils is also quite variable and seems to be a function of the absorption. In light soils the ammonia quickly finds its way into the deeper layers unless there is a supply of CaO present; in heavier soils, most of the ammonia is held in the surface three or four inches. A slightly alkaline reaction is beneficial to the conservation of ammonia. Calcium carbonate has little effect upon the distribution of ammonia in soils. Everything else being equal, ammonium sulfate should be applied shallower in light than in heavy soils.

5. Potash or acid phosphate tends to lower the mean distribution of the ammonia.

6. A correlation exists between the absorptive capacity of a soil for ammonia and the depth of its distribution; the greater this capacity the nearer the surface will it remain.

ACKNOWLEDGMENT

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THE NITRIC NITROGEN CONTENT OF THE COUNTRY ROCK[1]

A Contribution Regarding the Origin of Nitre Spots in Certain Western Soils

By

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I. Historical

The progress of the work upon the general problem of the origin of the nitre spots in certain western soils has developed several different points of view. The fact that certain spots in western cultivated soils were unusually rich in nitrates was first observed by Hilgard (6, p. 68), who attributed their accumulation to the more rapid nitrification of the organic matter of the soil in the warm arid climate of the West when the moisture limit was removed by irrigation.

A number of years later an entirely different explanation was offered for a similar condition observed by Headden (3) in certain Colorado soils. Spots were observed on which nothing would grow and examination showed the soil to be rich in nitrates and also other alkali salts consisting of the chlorides and sulphates of calcium, magnesium, sodium, and potassium in varying amounts. Soil, which had been formerly productive and of great value, became non-productive and almost valueless. In many cases, valuable orchards were partially or entirely ruined by these accumulations. The nitrates present were attributed by Headden to the fixation of atmospheric nitrogen by the non-symbiotic bacteria. This conception has been further amplified by Headden (4, 5) and also by Sackett (7).

Our investigations (10; 12, p. 128) at the Utah Experiment Station, extending over a period of ten years, regarding the influence of irrigation water upon the production and movement of nitrates in irrigated soils, led u to an entirely different conception regarding the origin of these nitre spots. We had found that nitrification was not appreciably more rapid in arid soil than in the humid soil when measured by the nitrates

present in the soil at various depths and in definite seasons throughout the year and from year to year. For example, Warrington (15, p. 82) found at Rothamsted after lucerne that there was 3.3 parts per million of nitric nitrogen; in Utah, Stewart and Greaves, found 0.8 parts per million in irrigated land and 1.8 parts per million in dry-farmed land. In wheat soil after clover, Warrington found at Rothamsted 2.2 parts per million; while in Utah, Stewart and Greaves found 0.8 parts in dry-farm land. After fallow Warrington found 1.3 parts of nitric nitrogen per million; while Stewart and Greaves in Utah found 5.4 parts per million. These facts, together with the additional fact that wherever Dr. Hilgard or Dr. Headden had reported the data from the nitre spots they also always reported the presence of additional amounts of other alkali salts, led us to suspect that the nitre spots were the direct result of the leaching and concentration of the nitrates by the movement of the ground water. This conclusion received considerable support when a close examination (11) of Dr. Headden's results showed clearly that the nitric nitrogen and chlorine *in any given nitre spot* varied in the same ratio from year to year or period to period within a year.

A preliminary investigation (8) showed that the country rock adjacent to the affected areas was impregnated with alkali salts including the nitrates. These results were so significant and important as to warrant continued additional work along the same lines. It seemed imperative that we should learn more of the geology of the affected areas. This study led to extensive investigations regarding the nitrate content of the country rock and the geological history of the area, the results of which have been partially published (13, 14).

The former work reported the results of investigations regarding the nitrate content of the country rock of eastern Utah, western Colorado and southwestern Wyoming, and consisted of a study of the Jurassic, Cretaceous and Tertiary deposits of shale, sandstone, gypsum, ash and rock salt. It was found that the shales and sandstones of the Cretaceous and Tertiary were heavily impregnated with nitrate accumulations. *All Cretaceous material was found to contain nitrate.* Cretaceous sandstone contained a maximum amount of 0.293 per cent sodium nitrate, the shale contained a maximum of 1.026 per cent; the clay 0.115 per cent, the ash[1] 3.270, while the surface alkali soil contained 3.35 per cent. The Tertiary sandstone contained a maximum amount of 0.284 per cent, the shale 0.750 per cent, the clay 0.940 per cent, the ash, 3.280 per cent, while the surface alkali soil contained 0.232 per cent. While the Tertiary material contained a slightly lower amount, the greater extent of exposed area belong to this series. This renders a great area of soil derived from the Tertiary rock

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[1] Ash is a term used throughout this paper to indicate the mixture of dry fine clay and dry white crystals of alkali salts. This mixture is found over the clay hills just under a hard clay crust on the surface.

subject to nitrate accumulation. The maximum, minimum, and average amounts of sodium nitrate in the three classes of material are reported in Table A.

The Jurassic deposits are not so heavily charged with alkali and nitrate accumulations as are those of the Cretaceous or Tertiary.

TABLE A

PER CENT SODIUM NITRATE IN CRETACEOUS MATERIAL

	Maximum	Minimum	Average
Sandstone	0.293	0.005	0.055
Shale	1.026	0.003	0.104
Clay	0.115	0.002	0.039
Ash	3.270	0.005	0.870
Alkali	3.350	0.003	0.074
TERTIARY			
Sandstone	0.284	None	0.074
Shale	0.750	None	0.147
Clay	0.940	None	0.053
Ash	3.280	0.0002	0.236
Alkali	0.232	None	0.021
JURASSIC			
Sandstone	0.039	None	0.008
Shale	0.019	None	0.005
Ash	0.202	0.149	0.175
Alkali	0.017	0.017	0.017

The data presented in this paper are the results of a continuation of the investigations upon the nitrate content of the country rock of other portions of the state of Utah, the deposits of which belong partially to other geological series than the Cretaceous, Tertiary or Jurassic. The rock investigated belongs in part to the Triassic, Permian and Pennsylvanian, but for convenience of discussion all material is grouped together from some central agricultural point.

II. METHOD OF INVESTIGATION

The samples were all collected from the southwestern part of Utah or the northwestern part of Arizona in the manner already described. The collections were made in the summer of 1914. The nitric nitrogen and other alkali salts were determined in all the samples collected. The discussion of the significance of the alkali accumulations in the country rock is reserved for a future publication but for convenience the total amount of soluble salts is here reported together with the ratio of nitric nitrogen to the total salts present.

Fifty grams of the finely ground rock were placed in a large bottle with 1000 c.c. of distilled water and placed in a shaking machine for 8 hours. The solution was separated by filtration through a Chamberlain-Pasteur filter. The nitric nitrogen was determined in the soil extract by the aluminum reduction method.

III. The Country Rock at St. George

The results of the analysis of the rock north of St. George, Utah, are reported in Table I, which for convenience of study is subdivided into four divisions. It may be seen from a study of the results presented that there are many times as much nitric nitrogen in the original rock near Santa Clara, southern Utah, as we found in the normal irrigated soils. Sample No. 323 contains over forty times as much as the maximum amount we found in our ordinary well cultivated soils.

Even the average amounts in eight samples of rock is sixteen times the maximum in productive soils of Utah.

TABLE I

NITRIC NITROGEN CONTENT OF THE COUNTRY ROCK
NORTH OF ST. GEORGE, UTAH

A.—GYPSUM

Field No.	Description and location of samples	Total soluble salts p. p. m.	Nitric Nitrogen	
			Parts per million	Per cent of total salts
319	Gypsum a few feet from No. 318..............	34,270	76.1	0.220
318	Gypsum and saponite west of No. 317.........	54,520	40.9	0.071
317	Gypsum 1¼ miles east of Santa Clara, Utah...	47,360	35.1	0.074
	B.—SHALE FROM TYPICAL CLAY HILL			
323	Disintegrated shale and dust near top of the hill	20,000	210.6	1.05
321	The dark undecomposed shale.................	7,120	198.9	2.79
322	Darker shale higher up than No. 321..........	8,000	40.9	0.512
	C.—VOLCANIC ASH			
313	Volcanic ash, Diamond Valley	6,520	31.2	0.47
	D.—BAUXITE CLAYS			
320	Bauxite near Santa Clara....................	3,440	17.6	0.51
	General average	29,989	81.4	0.71

The nitrates, as in many of the nitre spots, constitute only a small part of the soluble salts present in the country rock. As an average only 0.7 per cent of the soluble material is nitric nitrogen. The average amount of nitric nitrogen present is 81.4 parts per million while there is an average of 29,989 parts per million of total alkali salts.

The gypsum deposits as represented by Nos. 319, 318 and 317 contain large quantities of material soluble in water, an appreciable quantity of which is nitrate. The quantity is not large when considered from a commercial point of view, but when the immense quantity of the gypsum deposits is considered and their bearing on the material contributed to the

soil formation, the amount of nitrate present in these deposits is of considerable significance.

The samples of shale, Nos. 323, 321 and 322, were collected from a typical clay hill on which no vegetation was growing. These clay hills, "on which nothing will grow," are characteristic of many areas of southern Utah and western Colorado. And it is important to consider them very carefully in seeking a solution of the origin of the nitre spots.

This particular clay hill is fully as characteristic as those occurring in eastern Utah which have already been described. The characteristic ash-like condition was observed on the sides and top of the hill. Both the shale and ash material are rich in nitrate and water-soluble salts, although not so rich as some of those observed in eastern Utah. A photograph was taken of this hill and is reproduced in Plate I, figure I.

No. 313, a good representative of the extensive volcanic ash deposits of southern Utah, contains an appreciable amount of soluble salts which contain some nitrate.

TABLE II

NITRIC NITROGEN CONTENT OF THE COUNTRY ROCK
WEST OF ST. GEORGE, UTAH

Field No.	Description and location of samples	Total soluble salts p. p. m.	Nitric Nitrogen	
			Parts per million	Per cent of total salts
331	White shale 2 miles above No. 330............	41,040	450.0	1.10
330	Shale 30 feet below No. 329.................,	1,480	356.0	24.11
329	Shale 8 miles below St. George..............	5,480	216.0	3.99
326	Red and gray shale on banks of Rio Virgin....	3,880	134.0	3.46
332	Shale and sandstone........................	3,920	35.0	0.89
327	Alkali salts near No. 326....................	138,600	23.0	0.16
334	Ash-like soil underneath the clay.............	115,000	23.0	0.02
333	Sample of clay..............................	82,300	12.0	0.014
	Average	48,962	156.0	4.22

Eight samples of shale, alkali and clay were collected from the deposits west of St. George, Utah, down the valley of the Rio Virgin River. These deposits probably belong to the lower Triassic or upper Permian series. The results are reported in Table II. All of the material is rich in nitrates and other water-soluble salts. Sample 331, undecomposed shale, contains over 80 times as much nitric nitrogen as reported in our best agricultural soils either in Utah or at Rothamsted. The average amount present in all the material is over 30 times this amount. These facts emphasize the significance of the nitrates present in the undecomposed rock of large areas of the Arid West.

Ten samples of material were collected east of St. George up the valley of the Rio Virgin River. The samples were taken as we ascended in the Triassic series of deposits. These results are recorded in Table III.

Again there is a large quantity of soluble salts, part of which is nitrate; the nitrate seems to decrease in amount as samples are obtained higher in the series. Still there are appreciable quantities present. If this material were spread out and weathered into soil without any loss or gain in soluble material, the soil would be extremely rich in salts soluble in water. Considering the average amount present, each acre would contain 108,502 pounds or over 54 tons of material soluble in water per two million pounds of soil, which is roughly the weight of the plowed surface of soil to a depth of $6\frac{2}{3}$ inches. There also would be 892 pounds of sodium nitrate in this layer of soil. It should be remembered that the usual application of sodium nitrate as a fertilizer is about 200 pounds

TABLE III

NITRIC NITROGEN CONTENT OF THE COUNTRY ROCK
EAST OF ST. GEORGE, UTAH

Field No.	Description and location of samples	Total soluble salts p. p. m.	Nitric Nitrogen	
			Parts per million	Per cent of total salts
336	Dark shale on opposite side of hill from No. 335	6,560	468.00	7.13
341	Clay from same locality as No. 340............	70,080	64.40	0.090
338	Anhydrate gypsum just below No. 337.........	44,600	46.80	0.105
343	Shale north of bridge over Virgin River.......	37,600	35.10	0.093
344	Crest over shale near No. 343	109,320	35.10	0.032
337	Gypsum in valley on road to Hurricane.......	44,800	30.40	0.068
339	Shale interstratified with gypsum.............	46,800	22.40	0.047
335	Shale east of Washington....................	5,560	17.55	0.316
340	Cherty limestone east of Washington..........	46,440	11.70	0.025
342	Alkali just under sandstone..................	130,800	11.70	0.009
	Average	54,256	74.31	0.79

per acre. Is it any wonder that the application of irrigation water to such soil gives rise to the concentration of nitrates in spots which are rich in nitrates? To emphasize further the significance of the data, apply the same method of reasoning to sample No. 336. The plowed surface of such a soil would contain 5,816 pounds or nearly three tons of sodium nitrate per acre. With the proper control of the irrigation water this material is of great economic importance in the production of crops.

IV. THE COUNTRY ROCK OF NORTH ARIZONA

Nine samples of shale, clay, gypsum and alkali were collected in northwestern Arizona. The results of analysis are recorded in Table IV. The largest amount of water-soluble salts and nitrate are found in samples No. 350 which represents the clay crust at the base of the shale cliffs.

These samples are not so rich in nitrates as those in southern Utah, although again much more nitrate is present than is found in our best cultivated soils.

V. The Country Rock at Mt. Carmel

In Table V are recorded the results of analysis of material collected near Mt. Carmel, Utah, which is located about 100 miles from St. George

TABLE IV

NITRIC NITROGEN CONTENT OF THE COUNTRY ROCK
IN NORTHERN ARIZONA

Field No.	Description and location of samples	Total soluble salts p. p. m.	Nitric Nitrogen	
			Parts per million	Per cent of total solids
350	Clay crust at base of shale cliffs west of Fredonia, Ariz.	141,240	70.2	0.050
345	White gypsum east of Workman's spring.......	47,400	40.9	0.086
346	Red shale and gypsum near No. 375...........	46,240	40.9	0.089
352	Red shale	44,640	23.4	0.052
353	Red sandstone	1,520	23.4	1.540
347	Hard white material near Pipe Springs........	44,920	11.7	0.026
348	Ash near Fredonia	48,600	11.7	0.024
349	Brownish red shale 3 miles west of Fredinia...	45,920	11.7	0.026
351	Shale overlying the red shale................	46,240	11.7	0.025
	Average	51,858	27.3	0.212

up the valley of the Rio Virgin. In fact the river here has not cut through the Triassic deposits, but is now making a valley through the Cretaceous materials similar to those near Grand Junction, Colorado.

TABLE V

NITRIC NITROGEN CONTENT OF THE COUNTRY ROCK
NEAR MT. CARMEL, UTAH

Field No.	Description and location of samples	Total soluble salts p. p. m.	Nitric Nitrogen	
			Parts per million	Per cent of total solids
364	Sandy shale	118,120	152.0	0.128
366	Wet sticky clay	35,800	146.0	0.408
360	Red shale at base of hill...................	3,720	123.0	3.310
361	Red clay from base of hill..................	4,920	87.8	1.780
359	Near Mt. Carmel	2,720	76.0	2.790
357	Impure gypsum near Mt. Carmel.............	40,520	76.0	0.188
365	Brown shale	69,360	64.3	0.093
367	Disintegrated shale	38,320	58.5	0.153
362	Black coal shale	16,160	46.8	2.290
363	Argillaceous shale	9,720	29.3	0.301
358	Red shale at Mt. Carmel...................	3,560	23.4	0.065
355	Red sandstone higher up than No. 354........	1,840	23.4	1.220
354	Red sandstone in Kanab canyon.............	1,920	23.4	1.220
356	Red grit at Three Lakes, Kanab canyon.......	1,600	17.7	1.100
	Average	17,734	67.7	1.070

An examination of the data presented shows that the original rock is rich in salts including the nitrates, although not so rich as some of the other deposits previously studied belonging to this same series.

VI. The Country Rock at Cedar City

The rock material collected near Cedar City, Utah, probably belongs to the Tertiary deposits. The results obtained from the analysis of these samples are recorded in Table VI.

TABLE VI

NITRIC NITROGEN CONTENT OF THE COUNTRY ROCK
NEAR CEDAR CITY, UTAH

Field No.	Description and location of samples	Total soluble salts p. p. m.	Nitric Nitrogen	
			Parts per million	Per cent of total salts
376	Gypsum from old tunnel near No. 375	47,640	93.5	0.196
368	Drab shale on "State" road to Mt. Carmel....	9,920	58.5	0.590
369	Gypsiferous shale northeast of Cedar..........	48,160	41.0	0.085
377	Fine red ashy dirt near No. 376..............	50,440	29.3	0.058
378	Red clay from salt mines east of Cedar.......	21,640	23.4	0.108
370	Gypsiferous shale east of No. 369.............	46,200	11.7	0.025
371	Yellow ledge, disintegrated shale..............	41,600	11.7	0.028
372	Crust from top of shale.....................	42,080	11.7	0.028
373	Shale in the ledge..........................	42,960	11.7	0.027
374	Shale near intake to power system for Cedar..	2,160	11.7	0.540
375	Red shale with gypsum underneath No. 374....	43,800	11.7	0.027
	Average	36,055	28.7	0.160

The rock here is not quite so rich in nitrate as the Cretaceous or Triassic collected in the more southern part of the state, but still there is an appreciable quantity of nitrate. The alkali is more uniformly high in all the samples collected in this Tertiary material. An entirely similar condition was observed in eastern Utah. The Tertiary deposits were

TABLE VII

SUMMARY

District	Total soluble salts p. p. m.	Nitric Nitrogen	
		Parts per million	Per cent of total salts
North of St. George, Utah.............................	29,989	81.4	0.71
West of St. George, Utah.............................	48,962	156.0	4.22
East of St. George, Utah.............................	54,256	74.31	0.79
Northern Arizona	51,858	27.3	0.212
Vicinity of Mt. Carmel, Utah.........................	17,734	67.7	1.07
Vicinity of Cedar City, Utah.........................	36,055	28.7	0.16

richer in alkali and poorer in nitrate than the corresponding Cretaceous deposits. There is a far greater extent of Tertiary material exposed, however, and a greater area of soil derived from this kind of rock. Both the alkali and nitrate are more uniform in these deposits.

The average data for these various districts are brought together in Table VII. With two exceptions, less than one per cent of the total solu-

ble material is nitrate. These exceptions are in the upper part of upper Cretaceous at Mt. Carmel, and the Triassic, low in the series, west of St. George.

In the Cretaceous our results seem to indicate a decrease in nitrate with a decrease in the other water-soluble salts, while in the Triassic exactly the opposite condition is found, i. e., an increase in the nitrate content. All sections investigated are characterized by a high total water-soluble salt and nitrate content.

VII. RELATIONSHIP OF NITRATE CONTENT ROCK AND CULTIVATED SOILS

It should be remembered that it is only when the nitrates of the country rock are concentrated by the movement of the underground water over large areas that accumulations or spots occur in the cultivated soils. The abundance of nitrate occuring in the undecomposed shale adjacent to and underneath the cultivated soil is large enough to supply fully all the nitrate and other alkali salts present in these nitre spots.

The data presented here and in the previous publications are conclusive regarding the source of the nitrate accumulations in certain western soils. It is clearly demonstrated that the country rock adjacent to, underneath, and out of which the agricultural lands have been formed is abundantly supplied with the alkali salts and unusually large amounts of nitrates. Wherever and whenever the proper moisture conditions occur there is an accumulation of the alkali and nitrate in such large quantities as to render crop growth impossible. This condition occurs both in uncultivated and cultivated soils.

Such accumulations have been observed by us in many cultivated and virgin areas of Colorado, Utah, Wyoming and Alberta, Canada. In Colorado and Utah, the accumulations of alkali salts and nitrates have become so marked as to cause the death of many orchard trees. The source of the nitrate is directly traceable to the shale or sandstone, contributing to the soil or subsoil formation. The character of the exposed material may be noted from the accompanying photograph, Plate I, figure 2, taken of the shale hills northeast of Grand Junction, Colorado. The nature of the weathering and character of native vegetation may also be noted. The tops of the outlying clay hills are barren and close examination shows that under the clay crust there is an ash-like condition, previously noted, which is rich in alkali salts and nitrate.

This figure represents the upper part of the valley of the Grand River near the foothills. The agricultural land lies near the river. In these lands the river wash has filled in the depressions between the hills. The irrigating canals are higher up and in many places cut these clay hills near the upper part. The shale strata being nearly horizontal, the irrigating water penetrates the shale and follows the layers of shale down-

(ii—25)

ward to a point where the shale outcrops. The water rising to the sur-
face produced a bog, spring or characteristic "soap hole" and on the
evaporation of the water the salts including the nitrate are deposited,
producing a nitre spot. In many of the cultivated lands in Colorado and
Utah the lower point is covered with river wash two or three feet deep,
but the water, under more or less pressure carrying in solution the nitrate
and alkali, comes to the surface giving rise to the phenomenon noted.
The greater the amount of water used, of course, the greater the deposi-
tion of salts. Consequently, it was observed in some sections that during
the extremely dry years of 1910 and 1911 the trouble was more pro-
nounced than usual. During a normal or wet season there is not so much
water *maintained in the irrigating canals* and consequently not so much
passes through the clay strata and the trouble is not so pronounced. Since
these depressions are covered with river wash, one can very easily be led
astray into assuming that the land is level and uniform. The surface
may be level and uniform but the trouble arises from the *shale strata un-
derneath*.

In many areas the shale and sandstone are not exposed, still the trou-
ble from alkali and nitrate accumulations is manifest. Such a condition
may be observed in the Great Plains area, and is well illustrated by condi-
tions in Central Alberta, Canada. In Alberta the surface soil is of a
loess character. Recently a new irrigation system has been installed and
in some instances trouble has occurred from alkali accumulations arising
apparently on the highest part of a given farm. The alkali incrustations
have the characteristic brownish color due to the presence of the ni-
trates. What is the origin of this trouble since the shale and sandstone
is not exposed? Close observation by digging or examination of other
natural excavations, such as river banks, will show that the Cretaceous
shale is present in this entire area and is merely covered over by deposits
of glacial soil material to varying shallow depths. Where the alkali and
nitre indications arise the undecomposed shales may be often found at
from 3 to 6 feet. This shale is of the same geological age as that in Utah
and Colorado, and is rich in soluble salts.

In Alberta where the trouble is experienced, the irrigating canals, as
in Utah and Colorado, have cut the alkali bearing strata higher up. The
water follows, often for two or three miles, the almost horizontal strata
until it outcrops at the surface on some gentle slope in the form of an
alkali bog, or as it is locally called "soap hole," which is at first very
small in size but gradually increases until large areas of land are ruined.
Whenever the alkali and nitre spots are evident, close examination will
reveal the presence of the alkali or nitrate bearing shale, sandstone or
other rock.

VIII. The Relationship of the Alkali to the Nitrate Accumulations

The nitrates are not uniformily distributed through the affected areas. Certain spots may be rich in nitrate while others contain comparatively little nitrate. Exactly the same condition may be observed with the chlorides or sulphates. Some spots may be largely composed of chlorides, while others may consist almost entirely of sulphates. This condition was observed in the study of the alkali content of the country rock. Certain samples of country rock from some areas were rich in the nitrate, while others from different areas were poor in nitrate. But in any given area or spot of cultivated soil the chlorine and nitric nitrogen increase or decrease in the same proportion, thus indicating a common origin. There is no reason to assume, however, a more uniform distribution of the nitrate than of the chloride or sulphate in the conception that the nitrates are derived from the preëxisting nitrates in the country rock.

The nitrates are not independent of the other alkali salts. Cases may be observed where the alkali is largely the sulphate or chloride, and, if so, the surface indications are white in nature. No case has been observed or reported where the nitrate accumulations occur independent of either the chlorides or sulphates. Consider, for example, a typical case cited by Dr. Headden to which attention has already been called by us (11). In 1907, a typical nitre spot (case 8) contained in the surface foot traces of nitric nitrogen, 20,217 pounds of chlorine and 98,000 pounds of total salts. Four years later new determinations were made at the same spot with the following results: nitric nitrogen 621 pounds, chlorine 257,000 pounds, total salts 727,040 pounds. Is it not absurd to claim that nitrate is free from alkali when 1/3 ton of nitrogen is accompanied by 128 tons of chlorine and 313 tons of total salts? And the increase of 1/3 ton of nitric nitrogen has been accompanied by an increase of 118 tons of chlorine and 313 tons of other salts. That is, in this characteristic nitre spot in cultivated soil the nitric nitrogen is only 0.08 per cent of the total salts present. An examination of the data presented by us will show that there are few cases where the proportion of nitric nitrogen to total salts in the country rock is so small as this. Furthermore, we can hardly conceive of the addition of 313 tons of the chlorides and sulphates of sodium, potassium or magnesium to even our best agricultural soils and expect to obtain any growth of crops at all. The nitre spots are not independent of these other salts.

Entirely similar conditions have been noticed by us in our examination of the country rock. Small amounts of nitrate have been accompanied by large amounts of other salts in the rock itself *with local concentrations of nitrate accompanied by the other salts in the ash and alkali*

crust at the surface wherever moisture conditions are such as to cause a large evaporation of the alkali and nitrate bearing water.

And certainly there is no question that the alkali is due in a large measure to the marine deposits in the shale and deposited in the old epicontinental seas of upper Triassic, Cretaceous, and Tertiary times. The shales and sandstones are abundantly supplied with those salts. The Triassic below St. George, Utah, contains over 50 tons of salts per acre to a depth of 6⅔ inches. The Tertiary shales in the Uinta Basin are so rich in salts that costly attempts to build irrigating canals through these shales have been a failure, due to the dissolving and disappearing of the canal banks, being carried away in solution by the irrigating water. The nitrate accumulations are not independent of the alkali salts but intimately connected with them.

IX. THE RELATIONSHIP OF THE NON-SYMBIOTIC BACTERIA TO THE NITRATE ACCUMULATIONS

As the nitre spots slowly develop by the concentration of the alkali salts which also include the *nitrates* and *phosphates* of calcium, magnesium, sodium and *potassium,* ideal conditions are temporarily produced for plant nutrition. For two or three years before the soil is rendered non-productive phenomenal growth of crops is obtained due to the presence of all plant-food in the highly available condition. Conditions for the growth of the bacteria must also be temporarily more favorable. It is not surprising, therefore, that the non-symbiotic bacteria, especially the azotobacter, have been observed in these spots and undue significance placed on their presence. As the nitre spots develop, however, the concentration of alkali and nitrates becomes too great for the growth of either the higher or lower plants.

The fixation of nitrogen by the non-symbiotic bacteria in the ordinary dry-land soil in Utah, which is free from alkali and nitrate accumulations, is far greater than in the nitre areas, and yet we find no nitrate accumulations in such soils. Thus Sackett (7, p. 28) reports a maximum fixation of 15.8 mg. of nitrogen, per 100 gm. of soil from the nitre areas, *while Greaves (2) reports a maximum of* 51.8 *mg. of nitrogen fixed in the soils of Utah which are free from the nitrate accumulations.* The average amount fixed in the 32 samples collected by Sackett in Colorado from the nitre areas was 7.4 mg., *while Greaves found an average amount of* 12.2 *mg. in the* 31 *samples of dry-farm, alkali-free soil in Utah.*

These same dry-farm soils, which show a far greater fixation of nitrogen than the nitre soil, have been shown (8) to contain only normal amounts of nitrates. The amount in no case exceeds 6 parts per million, yet these soils have been cultivated for a period of over fifty years. The non-symbiotic bacteria, which are *active* and more *abundant* in the adja-

cent virgin soil than in the nitre soils, have had unlimited time during the past ages to produce the nitrate, yet the average nitrate content does not exceed 1.04 parts per million as an average of 22 separate determinations from soil of a wide area in the Cache Valley. *These dry-farm soils are also alkali-free.*

Finally, it must be remembered that the nitre spots are always characterized by a brown color. The nitrates themselves are colorless. The color is due to colored organic material. Bacteria are not necessary even for the production of this color.

Characteristic nitre spots have been produced by us at will in the laboratory in the following manner: 300 gm. of a rich greenhouse soil were weighed out into an evaporating dish which was then filled with a 10 per cent solution of sodium nitrate and allowed to evaporate slowly by the sun's rays without disturbing the dish or soil. When the soil became dry all of the characteristic indications of the nitre spots were present. The surface soil was highly colored, brownish in appearance. A thin crust was present underneath which was the characteristic mealy condition noted in the field. The artificial nitre spots were typical and they could be produced in this soil by adding the same amount of nitrate in the solid form and irrigating the soil with a saturated solution of mercuric chloride, or a 5 per cent solution of carbolic acid. On the crystals of mercuric chloride, which were finally deposited on the surface of the soil, was also deposited the rich brown color or "pigment" characteristic of the nitre spots. The soil itself, however, was harder than in the absence of the antiseptic. In a check experiment, evaporation of an equivalent amount of water from the same amount of soil failed to produce the color or other characteristic indications of the nitre spots. Surely this definitely eliminates the bacteria as the cause of the production of color as definitely as they have been eliminated as the cause of the production of the nitrates. The non-symbiotic bacteria are not essential to the production of the color or the nitre spots. The bacteria themselves are only incidental and under the given conditions are of no economic significance whatever.

The color is produced by the solvent and decomposing action of the nitrate, especially sodium and potassium nitrate upon the organic matter of the soil. In all soils or manure, there occur more or less considerable amounts of colored organic compounds, the solubility of which can be increased by various kinds of treatment. Thus, in the official humus determination it is necessary to treat the soil with an acid to decompose the calcium or magnesium salts of the organic acids present, after which they are readily soluble in the ammonia solution. The calcium or magnesium salts are insoluble, while the ammonium salt is soluble and *highly colored*. Likewise, in the soil of the nitre spots the calcium or magnesium salts of the colored organic acids are insoluble but are converted

into soluble compounds by double decomposition when sodium or potassium nitrate is present as already described (14).

X. Nitre Soils Not Limited to a Single Geological or Geographical Area

The nitre soils have been observed in widely separated portions of Utah, Colorado and Wyoming. They have been observed in cultivated and uncultivated soil derived from the shales, sandstones, limestones and marls of the Cretaceous, Tertiary, Juriassic, Triassic and Permian. The conditions are more pronounced in the soils derived from the Cretaceous and Tertiary. The nitre soils have been observed also in the Great Plains Area such as Central Alberta, Canada. While the conditions are more pronounced in arid soils, similar conditions have been observed in humid soils.

An interesting case of a characteristic "nitre spot" occurring in a humid climate is reported by Cameron (1, p. 36), although not recognized by him as such, possibly because his report was made prior to the discovery of the importance of the problem in the Arid West. This particular spot occurred on the Maryland Experiment Farm at College Park and was first reported by Professor Whitney. A sample of this material was secured and on analysis gave the following results:

$CaSO_4$	$CaCl_2$	$Ca(NO_3)$	$Mg(NO_3)_2$	$NaNO_3$	KNO_3
1.86	7.55	51.20	20.68	12.47	6.24

That is, over 50 per cent of this material is calcium nitrate, while over 90 per cent of the soluble parts is in the form of nitrates. The total soluble material in the "crust" was 1.83 per cent. This spot had the characteristics of the nitrate spots occurring in the Arid West including the hard crust on the surface and the "dark brown color." The characteristics are all present: (1) a high nitrate content, (2) a hard crust, (3) presence of other soluble salts including chlorides and sulphates, (4) dark brown color or "pigment." No mention is made of the mealy condition underneath the crust, but since this is due to the presence of soluble salts, undoubtedly closer examination of this spot would have revealed its presence. An examination of the country rock underneath or adjacent to this soil would certainly be interesting.

XI. Utilization and Reclamation of the Nitre Soils

The amount of the nitrate in a widely disseminated condition in the shales and sandstones of the area is enormous and if its distribution be properly controlled by the intelligent use of the irrigation water so as to prevent undue accumulations important economic use may be made of the nitrate present. When, however, the accumulations become so excessive as to prevent plant growth resource must be made to artificial drainage.

But one of the very discouraging features of this trouble is the fact that the ordinary type of drainage is inadequate to obviate the condition. Often drains established in the usual manner will not be flowing, yet the condition complained of is very pronounced on parts of the farm. This is due to the close, impervious structure of the soil which does not readily permit the lateral movement of water. Special drainage adapted to this condition by tapping the source of water which produces the bog or "soap hole" with a drain, will become effective. The condition also will be much benefited by cementing the irrigating canals at the point of contact with the alkaline shale ridges, thus preventing the direct entrance of the irrigating water.

One must not be led astray regarding the necessity of drainage from a study of the deep underground water supply. Misleading information may be obtained from a study of the wells used for domestic water supply. Our investigations have clearly demonstrated that some members of the geological series of shales and sandstones contain greater quantities of salts than others, and that some members are largely free from salts. The farmer in digging a well seeks good drinking water and usually finds it by driving in the river wash or through the alkali and nitrate bearing strata. This is well illustrated at Lyman, Wyoming. The shallow wells are all so charged with salts as to render them unfit for drinking purposes. Deeper wells which penetrate through the alkali-bearing strata into gravel and sand underneath furnish good drinking water.

Acknowledgment

Conclusions

1. Certain soils in western arid America contain spots which are rich in nitric nitrogen and contain in some instances several hundred times as much nitric nitrogen as occurs in normal cultivated productive irrigated soil.

2. These spots are locally known as "nitre spots."

3. Three theories have been presented regarding the origin of these accumulations: (a) Hilgard's conception was that the accumulations were due to the more rapid nitrification of the organic matter of the soil in arid climates. (b) Headden maintains that they are due to the fixation of the atmospheric nitrogen by the non-symbiotic bacteria. (c) Stewart and Peterson believe that they are the direct result of the leaching of the nitrates out of the preëxisting deposits in the country rock and locally concentrated by seepage.

4. The country rock adjacent to the affected areas and which has contributed to the soil formation is rich in nitrate and contains such an abundance of this material as fully to account for the accumulations noted.

5. The nitrate is transported from the original rock by means of seepage water. It is transported more rapidly where the water escapes from leaky irrigating canals cutting shale strata, thus allowing the seepage water to follow the shale strata to the point of outcrop. Nitre spots are produced where such seepage water rises and evaporates.

6. The nitrate deposits are not limited to the country rock of a definite geological series. They have been found in large quantities in the Cretaceous, Tertiary and Triassic with smaller quantities in the Jurassic.

7. The nitrate accumulations occur in the uncultivated soil wherever the water conditions are such as to cause the concentration of the nitrates in any given area.

8. The accumulations in the virgin soil possess all the characteristics of the nitre spots in cultivated soil, i. e., (a) a high nitrate content, (b) the presence of excessive quantities of other soluble salts, (c) brownish color, (d) thin crust over surface, (e) mealy or ash-like condition under the hard crust, and (f) a moist, sticky, glistening soil beneath the ash material.

9. Characteristic nitre spots may be produced artificially in the laboratory with a rich greenhouse soil and an excess of sodium nitrate. They are produced equally as well in soil rendered sterile by treatment with a saturated solution of mercuric chloride or 5 per cent solution of carbolic acid.

10. The non-symbiotic bacteria are not essential to the production of the nitrates or of the color found in the nitre spots. Their presence in these nitre soils is only incidental.

11. The nitrates of the nitre spots of the cultivated soils are derived from the preëxisting accumulations occurring in the adjacent country rock and transported by the movement of underground water brought to the surface by exposure of the rock outcrop and there deposited by the evaporation of the water.

12. The brown color of the nitre spots is due to the solvent and decomposing action of the nitrates on the old organic compounds of the soil.

13. The source of this old organic matter, like the nitrate, is in the shale and sandstone of the area which is coal and oil bearing.

14. The nitrate accumulations occurring in the country rock, like those noted in the soil, are always accompanied by excessive accumulations of other water-soluble salts.

15. The alkali salts in the affected area are derived from the preëxisting salts occurring in the country rock.

16. These nitre spots are not limited to any single geological horizon or geographical area.

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PLATE I

Fig. 1. Photograph of typical clay hill north of St. George, Utah, from which samples of shale were taken.

Fig. 2. Photograph taken in the shale hills northeast of Grand Junction, Colorado, showing the character of the exposed material, the nature of the weathering and the character of the native vegetation.

Fig. 1
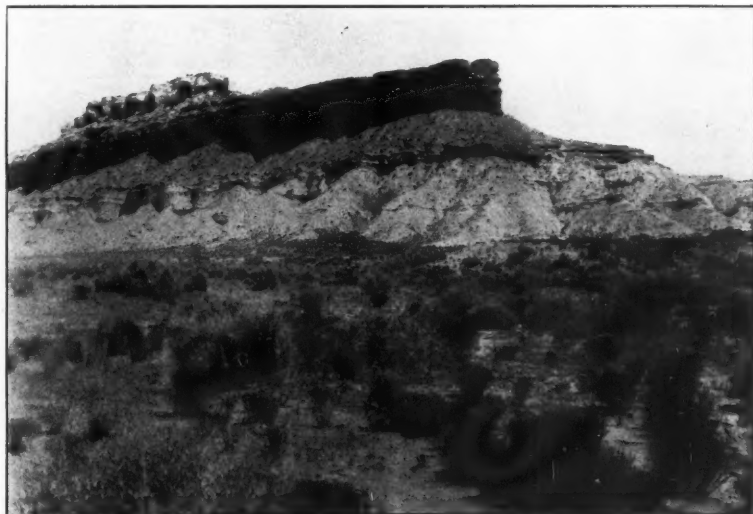
Fig. 2
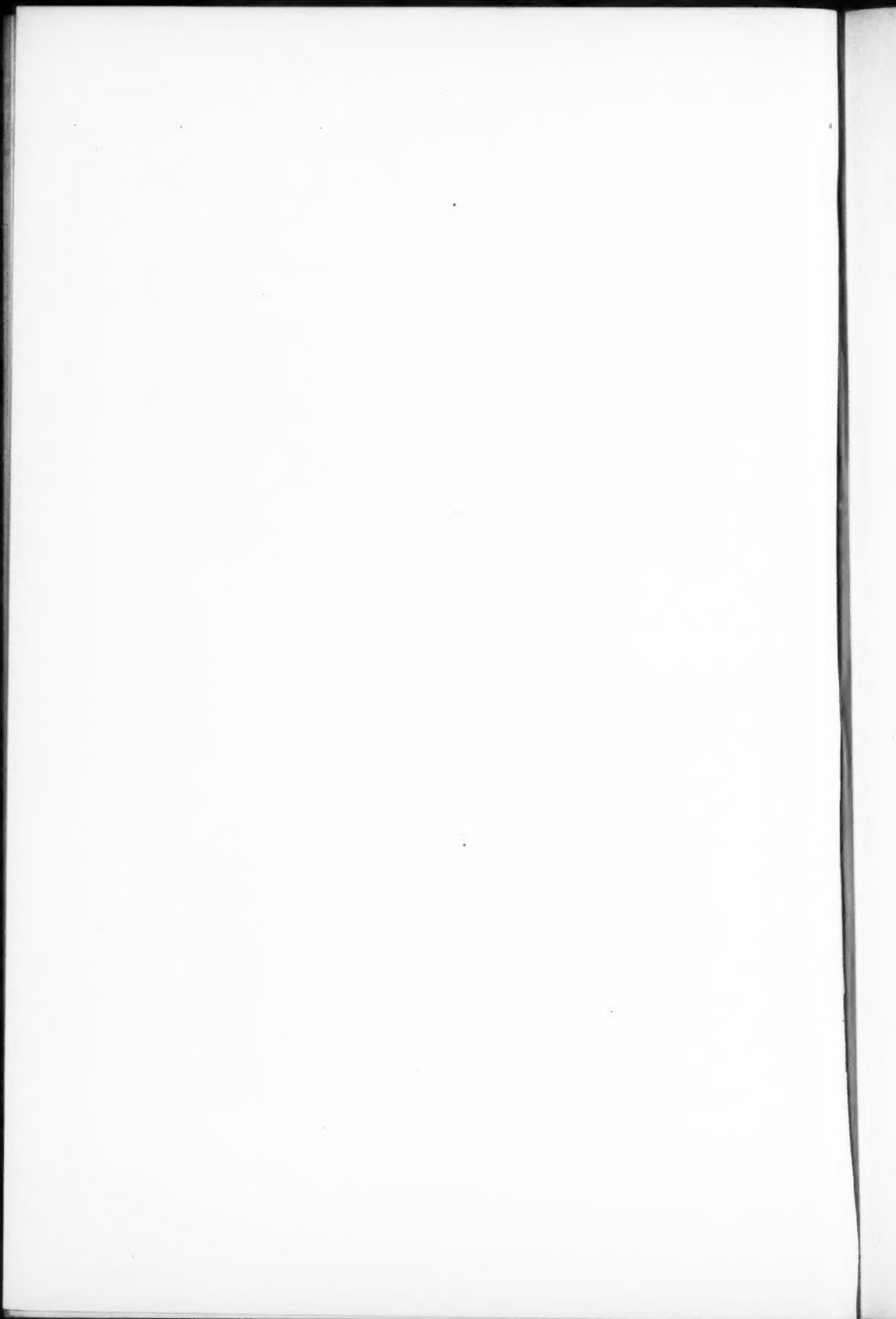
PROTOZOA, AS AFFECTING BATERIAL ACTIVITIES IN THE SOIL[1]

By

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INTRODUCTION

The theory proposed by Russell and Hutchinson (7, 8) that the protozoa act as a factor detrimental to soil bacteria and, for that reason, to soil fertility, has resulted in a great deal of work on the life of protozoa in the soil in general, and particularly on their behavior toward partial sterilization. The latter is supposed to destroy the protozoa, allowing the bacteria to multiply rapidly and liberate a larger amount of plant-food. Some of the data brought to light by these investigations goes to support this theory, while much of the work, particularly that of American investigators, does not find any basis for its justification.

HISTORICAL

Without taking up the full bibliography on the subject, since it can be found in most of the recent publications, attention will be called only to a few of the recent investigations which have a direct bearing upon the work to be presented. Russell and Hutchinson (7, 8) have shown that there are organisms in the soil which act detrimentally upon bacterial numbers and activities; the number of bacteria found in the soil at any time is not a simple function of the temperature, moisture content or other conditions of the soil, but depends on the difference in activity of the bacteria and the detrimental organisms. After the detrimental organisms are killed by antiseptics or heating the soil to 55° to 60° C. there is a rise in bacterial numbers and ammonia production in the soil; the detrimental organisms have been identified with the active protozoa in the soil.

This influence of antiseptics upon soil and the microörganic activities in it has been subjected to a great deal of study. Several investigators claim that the antiseptics act as a direct stimulant upon the bacterial flora of the soil. Hiltner and Störmer (4) believed that the bacterial flora of the soil consists of harmful and beneficial organisms; the antiseptics suppress the activities of the harmful bacteria, thus allowing the beneficial ones to multiply rapidly and liberate a greater amount of plant-food.

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The action of heat upon soil is explained by some investigators to be due to the destruction of toxins in the soil, although the presence of such substances has not been as yet definitely established. Greig-Smith (3) did not find any limitation in the number of soil bacteria upon adding suspensions of protozoa. Comparatively large amounts of volatile antiseptics when added to the soil did not destroy even the large ciliates. The effect of heat was of a different character upon the growth of bacteria. He concluded that the toxins and nutrients of the soil are alone concerned with the changes that occur when soils are heated or treated with volatile antiseptics; the protozoa have little or no action in limiting the numbers of soil bacteria.

Working with "sewage-sick" soils, Russell and Golding (6) have shown that they can be improved by partial sterilization: antiseptics and heat will put the detrimental factor out of action; the detrimental factor was similar to the one found by Russell and Hutchinson (7, 8) in ordinary soils, but was more pronounced. Similar results have been obtained by Russell and Petherbridge (9) in their study of "greenhouse-sick" soils. Russell and Buddin (5), studying the effect of antiseptics upon soil, found that toluene caused first a decrease and then an increase and also a change in type in the microörganic population of the soil, the suspension of nitrification and a marked increase in ammonia production. Gainey (2) reported that small quantities of CS_2, toluol and chloroform exerted a stimulating effect upon the bacterial numbers, but had no appreciable effect upon the number of types of protozoa present. Cunningham (1), adding cultures of protozoa to bacteria, concluded that soil protozoa exercise a decided limiting effect on the numbers of bacteria and their activities in the soil.

The author (12) has shown previously that the presence of protozoa acts detrimentally upon bacterial numbers in the soil, but has no appreciable influence upon ammonification by bacteria. This detrimental effect of protozoa upon the bacterial numbers and their non-detrimental effect upon ammonification in the soil was explained by one of the following assumptions: (1) if the protozoa destroy bacteria, they destroy non-ammonifying organisms; (2) the protozoa themselves may take part in the process of ammonification; or (3) the disintegration of the bacterial cells results in decomposition products which might be responsible for high ammonia production.

Sherman (10) found by using a synthetic bacterial soil flora, free from protozoa, that the soils containing protozoa gave lower bacterial counts. He has shown further that volatile antiseptics may destroy some protozoa, but not all of them, leaving ciliates, flagellates and amoebae. The maximum number of bacteria was not found while the protozoa were depressed by the action of antiseptics, but the development both of bac-

teria and of protozoa subsequent to treatment with volatile antiseptics ran parallel. Bacterial flora in soils containing protozoa and free of protozoa behaved in exactly the same way when exposed to different conditions of temperature and moisture content.

It is seen from the short historical review presented that the question of influence of protozoa upon bacterial numbers and activities in the soil, as well as of the actual conditions created in the soil by the action of antiseptics, which stimulate bacterial activities, is still undecided. One of the errors made by several investigators is the comparison of results obtained from entirely different soils. The soils of this country are different in their content of organic matter and perhaps of protozoa, from the "sick" soils of England. Dr. Löhnis has suggested to the author that there might be two classes of protozoa in the soil: useful and harmful. In ordinary cultivated, well aerated soils with a low content of organic matter, the useful protozoa may predominate. While, when soil is kept under certain conditions, such as high temperature, high moisture and high content of organic matter for a long time, harmful protozoa may develop, and this condition may lead to soil "sickness," as in the case of the "greenhouse" and "sewage-sick" soils studied by Russell and his associates. The problem was then to try to produce "sick" soils, the history of which should be known, as well as the activity of protozoa in those soils. This paper is limited to the study of the interaction between protozoa and bacteria in the soil, without going into details concerning the occurrence and numbers of protozoa in the soil.

EXPERIMENTAL

Methods of study. A clay soil classed by the Bureau of Soils as Penn loam and a light Sassafras loam were used for this work. The soils were divided into 3 portions: to one was added 20 per cent of fresh stable manure, and to another 20 per cent of finely cut green alfalfa; the third portion was left untreated. The soils were distributed, in 100-gm. portions, in tumblers, and moisture added equivalent to 70 and 100 per cent of the water-holding capacity of the soils. The tumblers containing the soils thus differently treated were then incubated at 3 different temperatures: one set at 30° C. in an electric incubator; the other set in the laboratory, the temperature of which ranged from 18° to 22° C.; and the third set was placed out-of-doors and kept there from October 19, 1915, when the experiment was started, until the beginning of July, 1916, when it was completed; a few tumblers were lost during that period, due either to the action of the frost outside, or to breakage.

The sets of tumblers representing the two soils were treated differently. Out of the tumblers containing the Sassafras soil representative samples, for the determination of bacterial numbers and their ammonify-

ing efficiency, were taken at the end of 37, 156 and 230 days after the experiment was started. At the end of the experiment (after a period of 230 days) the soils were divided into 3 portions: one set was left as a check; the second set was treated in Erlenmeyer flasks at 65° C. for 5 hours; the third set was treated with 4 per cent toluene for 48 hours, then spread out, and the toluene was allowed to evaporate for 48 hours. After the bacterial numbers were determined in the three sets differently treated, the ammonifying efficiency of each portion was also determined.

The set containing the Penn loam soil was kept untouched until the end of the experiment (230 days). The 100 gm. of soil from each tumbler was then divided into 3 portions; one of these portions also was treated with toluene, one with heat, and one portion was left untreated, in a manner similar to the Sassafras soil portions. However, the bacterial numbers were determined in the toluene treated soils at the end of 48 hours without allowing the antiseptic to evaporate, since, as was found in the case of the Sassafras soils, the bacteria multiplied rapidly during the 48 hours of evaporation. The proper amount of moisture was then added to the portions thus treated and allowed to incubate at 22° C. for, 30 days, after which period bacterial counts were made again and the amount of ammonia formed in each portion determined by distilling with MgO.

The bacterial numbers were determined by plating out a 200,000 dilution on modified albumen agar (11). The ammonifying efficiency of the bacteria was determined by sterilizing 100 gm. of Sassafras soil to which 155 mg. of N. in the form of dried blood and proper moisture content were added, then inoculating with 1-c.c. suspensions of the proper soil made by shaking for 5 minutes 10 gm. of the soil with 100 c.c. of sterile water. These were allowed to incubate for 12 or 28 days and the amount of ammonia determined by distilling with MgO. In the case of the Penn loam soils this method of procedure was not followed; only the amount of ammonia formed in the soil itself was determined.

This experiment was not planned to be an exhaustive one; it was intended originally to get an idea for certain lines of attack upon the probable activities of protozoa in the soil. For that reason such small portions of soil have been used, since with the different treatments a large amount of space and time was required. The author merely wanted to learn whether one could get an idea about the possible relationship between the partial sterilization of the soil and the microörganic activities, by making the conditions favorable for the protozoa, and thus breeding them in the soil, so as to have side by side soils rich in protozoa and soils poor in protozoa; soils in which protozoa were known to lead an active life at all times, and soils in which no protozoa were ever found to be active; using the two types of soil made "sick" to a certain extent, as far as the protozoa go.

The bacterial numbers and the ammonifying efficiency of the Sassafras soils differently treated are presented in Table I; the effect of partial sterilization by heat and toluene upon bacterial numbers and the ammonifying efficiency of the same soils is presented in Table II; and the results of the work with the Penn loam soils differently treated are given in Table III.

TABLE I

DEVELOPMENT OF BACTERIAL NUMBERS AND THEIR AMMONIFYING EFFICIENCY
IN SASSAFRAS SOILS KEPT UNDER DIFFERENT CONDITIONS OF
MANURE, MOISTURE AND TEMPERATURE

Soil Treatment			Protozoa, Active	Millions of Bacteria per gram of Soil			Ammonia Accumulated in mg. N. in 100 gm. of Soil plus Dried Blood		
Manure	Moisture %	Temperature °C.	Protozoa, Active	After 37 Days	After 156 Days	After 230 Days	After 37 Days[1]	After 156 Days	After 230 Days
Stable	70	out-of-doors	0	153.0	22.9	21.0	64.76	26.00	69.30
Stable	100	20	C.F.[2]	25.0	8.7	7.0	21.26	56.80	59.22
Stable	100	30	C.F.	3.0	5.8	1.2	31.95	22.30	73.58
Alfalfa	70	out-of-doors	0	50.6	45.6	41.2	70.64	93.60	64.89
Alfalfa	70	30	F.	13.8	9.2	11.2	12.21	21.50	73.71
Alfalfa	100	out-of-doors	C.F.	43.2	41.2	21.6	52.58	30.65	60.87
Alfalfa	100	20	C.F.	7.6	6.5	8.0	25.48	18.30	65.53
Alfalfa	100	30	C.F.	9.0	10.9	4.5	13.92	14.55	63.33
None	70	out-of-doors	0	2.4	7.6	4.9	58.40	61.30	72.45
None	70	20	0	2.8	6.9	3.0	68.58	58.60	68.04
None	70	30	0	1.0	1.9	1.1	69.77	16.90	77.83
None	100	out-of-doors	0	3.0	6.1	4.2	65.37	52.80	74.97
None	100	20	0	1.2	3.0	5.0	64.02	50.95	69.30
None	100	30	0	1.0	2.1	1.1	47.58	26.60	75.00
Average ...	.....	out-of-doors	....	50.4	24.7	18.6	62.35	52.87	68.49
Average ...	.....	20	....	9.2	6.3	5.8	44.84	46.16	65.52
Average ...	.....	30	....	5.6	5.9	3.8	35.09	20.37	72.69
Average ...	70	....	....	37.3	15.7	13.7	57.39	46.30	71.04
Average ...	100	....	....	11.6	10.5	6.6	40.27	34.10	67.73

[1] After 37 and 156 days a 12-day incubation period was used for the determination of ammonifying efficiency; after 230 days a 28-day incubation period was used.

[2] C.—Ciliates; F.—Flagellates. Only active protozoa have been determined.

In Table I are shown the changes in bacterial numbers and their ammonifying efficiency in a Sassafras soil, containing varying quantities of manure and moisture, and kept under different temperatures. Protozoa were found in all soils, but were found to be active only in the soils to which 20 per cent of stable manure or green manure was added and at the higher moisture contents. This confirms the idea expressed before by the author (12) and also by Sherman (10) that the organic matter and high moisture content favor the activity of protozoa. The bacterial numbers were much higher in the manured soils than in the unmanured, which is self-understood, since the addition of available organic matter

usually stimulates bacterial activity. But when the different periods are compared, an important difference will be found between the bacteria in the manured and in the unmanured soils; while the bacteria in the manured soils, with few exceptions, decreased steadily with the time of incubation, the bacterial numbers of the unmanured soils increased in every instance from 37 to 156 days, then slightly decreased to 230 days, always remaining above the first counts. This may be explained by the fact that in the soils containing a high percentage of organic matter in the form of stable manure or green manure, fermentation sets in readily and this stimulates bacterial activities; the final decomposition of the manure and perhaps the production of organic toxins may check the bacterial development after a certain length of time; this occurrence may not take place in the soils to which no manure has been added. There does not seem to be a great deal of difference between the ammonifying efficiency of the organisms from the manured and the unmanured soils. The different periods cannot be compared for the ammonifying efficiency of the microörganisms, since in the last case a longer incubation period was used.

As to the influence of the activity of protozoa upon the bacterial numbers, examination of the above table will show that there is probably a relationship between the two groups of microörganisms. The bacterial numbers were much higher in the absence of active protozoa (as far as could be shown by the present methods of study), and where the protozoa were found to be active there was a drop in bacterial numbers. This bears out again the contention of Russell and Hutchinson (7, 8) that the bacterial numbers are decreased in the presence of protozoa.

When the different temperatures of incubation are compared, the soils kept out-of-doors gave on the average, in all the three examinations, higher bacterial numbers and a higher ammonifying efficiency than those kept at 20° C., and the latter higher bacterial numbers and higher ammonifying efficiency (with one exception) than those kept at 30° C. The high temperature seems to have an injurious effect upon the bacteria; whether this is due to the lessening of the vitality of the organisms or to the more rapid decomposition of the organic matter, which sets free more organic toxins, cannot be decided as yet. The fact that the soils kept out-of-doors gave on the average higher bacterial counts in all instances, and stronger average ammonifying efficiency in all instances but one, may give support to the idea that bacteria are benefited by natural conditions and changes in temperature, since the soils froze and thawed many times during the winter. This cannot be explained by the fact that the low temperatures of the winter check the development of protozoa, and for that reason allow the bacteria to develop to larger numbers, as Russell and Hutchinson (8) maintain, since the soils kept outside had much higher bacterial numbers even before the freezing weather set in. Sher-

man (10) also came to the conclusion that the low temperatures have no stimulating effect upon the bacterial cultures containing protozoa.

The high moisture content seems to act injuriously upon bacterial numbers and their ammonifying efficiency, since in most instances the optimum moisture gave higher bacterial counts and had a stronger efficiency for producing ammonia than the soils of the higher moisture content.

The results brought out in Table II will throw some light upon the possible influence of protozoa on the bacterial numbers and their ammonifying efficiency in the soil, also the rôle which partial sterilization plays in the killing of protozoa.

The heating of the soil at 65° C. for 5 hours killed all the protozoa, except in one case, where small flagellates were left. On the other hand, the treatment of the soil with 4 per cent toluene for 48 hours, which was then allowed to evaporate for 48 hours, killed only the ciliates and large flagellates, leaving the small flagellates; in one case small ciliates were found after the toluene treatment, while in another case the small flagellates were also killed. Thus, when one speaks of the killing of protozoa by partial sterilization, he should be careful to modify his statement as to what kind of protozoa he has in mind. The ciliates and flagellates are two distinct groups of organisms, and their rôle in the fertility of the soil also may be distinct. This confirms Sherman's (10) results, that partial antiseptics fail to exterminate entirely the protozoa in the soil.

Only the heating of the soil killed all the protozoa, and only in that case can one speak of a bacterial flora free from protozoa, while the toluene treatment freed the soil only from the larger types of protozoa. When these results are compared with the bacterial numbers of the soil and their ammonifying efficiency, the results will be found to be striking. The heating of the soil greatly reduced the bacterial numbers in all instances, the average being 1,700,000 per gm. of soil as compared with 8,300,000 for the check. The soils treated with toluene gave on the average a higher bacterial count than the check. This was due to the fact that the toluene-treated soils were allowed to evaporate for 48 hours and the bacterial numbers were allowed to increase, since the count was made only at the end of that period. When an equivalent amount of soil suspension (0.1 gm.) was added to 100 gm. of sterile soil containing 155 mg. N. in the form of dried blood and allowed to incubate for 28 days, the bacterial numbers and ammonia produced determined at the end of that period, the average numbers were found to be 33,000,000 for the soils inoculated with the untreated portions, 45,000,000 for the treated soil, and 25,800,000 for the toluened soil. It looks as if the presence of protozoa had some effect upon the bacterial numbers; the heated soils, free from protozoa, gave much higher bacterial numbers than those in which the protozoa were present. The results on the ammonia accumula-

(ii—26)

TABLE II
EFFECT OF HEAT AND TOLUENE ON THE BACTERIAL NUMBERS AND THEIR AMMONIFYING EFFICIENCY IN SASSAFRAS SOIL

Manure	Moisture %	Temperature °C.	Treatment	Presence of Protozoa	Millions of Bacteria per gm. of Soil — At the Beginning	Millions of Bacteria per gm. of Soil — After 28 Days	Ammonia[1] in mg. N. Formed by 1 c.c. Suspension in 100 gm. of Soil plus Dried Blood
Stable	70	out-of-doors	check	C.F.[2]	21.0	117 0	69.30
Stable ...	70	out-of-doors	heat	0	0.9	11.0	81.25
Stable	70	out-of-doors	toluene	F.	85.0	90.0	61.06
Stable	100	20	check	C.F.	7.0	30.8	59.22
Stable	100	20	heat	0	0.6	14.9	65.03
Stable	100	20	toluene	F.	10.4	49.6	63.63
Stable	100	30	check	C.F.	1.2	102.0	73.58
Stable	100	30	heat	0	0.7	13.7	71.74
Stable ...	100	30	toluene	F.	13.3	12.2	52.90
Alfalfa ...	70	out-of-doors	check	C.F.	41.2	13.1	64.89
Alfalfa ...	70	out-of-doors	heat	0	2.0	90.0	43.86
Alfalfa ...	70	out-of-doors	toluene	F.	94.0	99.7	59.49
Alfalfa ...	70	30	check	C.F.	11.2	9.9	73.71
Alfalfa ...	70	30	heat	0	7.6	6.9	29.24
Alfalfa ...	70	30	toluene	F.	10.0	15.8	64.90
Alfalfa ...	100	out-of-doors	check	C.F.	21.6	84.4	60.87
Alfalfa ...	100	out-of-doors	heat	0	2.1	120.0	39.73
Alfalfa ...	100	out-of-doors	toluene	F.	49.0	28.3	52.02
Alfalfa ...	100	20	check	C.F.	8.0	16.4	65.53
Alfalfa ...	100	20	heat	0	1.1	19.1	44.10
Alfalfa ...	100	20	toluene	F.	22.7	16.8	69.93
Alfalfa ...	100	30	check	C.F.	4.5	26.6	63.33
Alfalfa ...	100	30	heat	0	4.0	300.0	45.36
Alfalfa ...	100	30	toluene	F.	3.5	8.6	61.74
None	70	out-of-doors	check	C.F.	4.9	10.1	72.45
None	70	out-of-doors	heat	0	1.4	8.0	51.03
None	70	out-of-doors	toluene	0	8.0	4.9	73.71
None	70	20	check	C.F.	3.0	10.3	68.04
None	70	20	heat	0	0.3	12.1	40.95
None	70	20	toluene	0	4.4	4.1	77.03
None	70	30	check	C.F.	1.1	7.0	77.83
None	70	30	heat	0	0.15	8.0	83.38
None	70	30	toluene	F.	0.9	9.1	74.34
None	100	out-of-doors	check	C.F.	4.2	11.0	74.97
None	100	out-of-doors	heat	F.	1.0	11.5	78.12
None	100	out-of-doors	toluene	C.F.	5.0	10.5	74.86
None	100	20	check	C.F.	5.0	18.6	69.30
None	100	20	heat	0	1.5	7.4	54.55
None	100	20	toluene	F.	4.7	7.1	67.88
None	100	30	check	C.F.	1.1	4.5	75.00
None	100	30	heat	0	0.3	7.2	67.41
None	100	30	toluene	F.	1.6	4.2	74.36
Average ..	.....	....	check	....	8.3	33.0	69.14
Average ..	.....	....	heat	....	1.7	45.0	56.84
Average ..	.....	....	toluene	....	22.3	25.8	66.27

[1] A 28-day incubation period was used.

[2] Presence of protozoa, not their activity, was determined. C.—Ciliates; F.—Flagellates.

tion are entirely different: the treated soils which at times gave the largest numbers of bacteria, frequently gave the smallest ammonia accumulation; the untreated and toluene-treated soils containing protozoa and fewer bacteria, gave higher ammonia accumulation.

These results are not in accord with Russell and Hutchinson's (8) conclusions. The presence of protozoa seems to check the bacterial numbers, but has no influence upon their ammonifying efficiency; as a matter of fact, the untreated soils containing ciliates and flagellates gave on the average slightly higher ammonia accumulation than the toluene-treated soils, which contained only flagellates. The ammonifying efficiency of a soil and its bacterial content do not seem to go hand in hand, but there appears to be a fair consistency. These results bear out the conclusions of the previous paper (12), that the protozoa seem to have a detrimental effect upon the numbers of bacteria, but not upon their ammonifying efficiency.

Of course, this method of attacking the problem of interrelationship between the protozoa and bacteria in the soil is open to severe criticism, since this study has been made on sterilized soil, where the conditions are absolutely non-comparable with ordinary soils. Not only the presence of protozoa, but also their active condition was demonstrated in all instances when inoculated into sterilized soil, if the organic matter and moisture content were high enough for them to be active. If a study is made merely of the two groups of organisms, not of the natural soil conditions, the sterilized soil affords a good means of doing it, unless there may be groups of protozoa (perhaps the harmful ones), which would not be active under these conditions. The whole problem in then changed, and we do not have to speak of the influence of protozoa, as a group, upon bacteria, but of certain organisms, which may not be protozoa at all, or which develop only when soil is kept under abnormal conditions.

The fact that the soils containing the full moisture-holding capacity, in which active protozoa were found in most examinations, gave lower bacterial counts and lower ammonifying efficiency than the soils with the optimum moisture, in which protozoa were not found to be active, might be used for the assertion that the protozoa act injuriously upon the bacteria and their activities in the soil. The same thing would hold true with the different temperatures of incubation. The higher the moisture content and the higher the temperature of incubation (up to a certain limit), the more active the protozoa are found to be. But these conditions give also lower bacterial numbers and lower ammonifying efficiency. Hence, if one would correlate the two it would look as if the protozoa produce that effect. But anyone who studies environmental conditions of organisms would say that increasing the moisture content above the optimum and the temperature above normal will lessen the vitality of the organisms, hence the decrease in bacterial numbers and their ammonifying effi-

ciency. By making the conditions abnormal the vitality of the bacteria is lessened, but these conditions seem to favor protozoan activity, and it was only natural for Russell and Hutchinson (7, 8) to correlate the two. Antiseptics seem to improve the conditions for bacterial activities; whether it is due to the killing of the less vital bacteria and large types of protozoa, thus producing a large amount of easily available organic matter; or to the destruction of soil toxins that have been formed under the abnormal conditions; or to the destruction of harmful organisms which might be protozoa, but not all the protozoa, since not all of them are destroyed; or to the improvement of conditions for other organisms, such as fungi, which would otherwise not be very active; or, finally, to all of those causes together and perhaps an entirely different one,—nothing definite can be said as yet.

To be able to get an idea, how partial sterilization of the soil influences not only the microörganisms in the soil, but the soil itself with the microorganisms in it, the Penn loam soils were treated differently, as has been outlined in the methods above.

Comparing the results obtained in Table III, it is seen that the action of heat and toluene have a beneficial effect upon the ammonia accumulated in the soils. While the average of the ammonia accumulated in 30-gm. portions of 16 untreated soils was 3.64 mg. of nitrogen, that accumulated in the corresponding portions treated by heat was 6.41 mg. N., and in those treated by toluene 4.43 mg. N. The same thing holds true with the bacterial numbers: the untreated soils contained on the average 8,600,000 of bacteria per gram, this number dropping to 4,100,000 in 30 days. The heat treatment reduced the bacterial numbers from 8,600,000 to 1,760,000

TABLE III

EFFECT OF HEAT AND TOLUENE ON BACTERIAL NUMBERS AND AMMONIA
PRODUCTION IN PENN LOAM SOIL

Soil Conditions				Millions of Bacteria per gram of Soil		Ammonia Produced in the Soil, in mg. N.
Manure	Moisture %	Temperature °C	Treatment	At the Beginning	After 30 Days	
Stable	70	out-of-doors	check	1.6	1.7	1.28
Stable	70	out-of-doors	heat	0.2	2.6	0.64
Stable	70	out-of-doors	toluene	0.9	5.0	2.30
Stable	70	20	check	6.2	3.5	0.77
Stable	70	20	heat	0.2	45.6	4.35
Stable	70	20	toluene	1.9	33.7 `	2.82
Stable	70	30	check	3.7	4.2	0.13
Stable	70	30	heat	0.6	6.6	0.90
Stable	70	30	toluene	3.9	17.8	1.66
Stable	100	out-of-doors	check	9.0	3.2	2.56
Stable	100	out-of-doors	heat	0.2	14.9	1.92
Stable	100	out-of-doors	toluene	3.0	14.2	1.79

TABLE III—Continued

EFFECT OF HEAT AND TOLUENE ON BACTERIAL NUMBERS AND AMMONIA
PRODUCTION IN PENN LOAM SOIL

Soil Conditions				Millions of Bacteria per gram of Soil		Ammonia Produced in the Soil, in mg. N.
Manure	Moisture %	Temperature °C.	Treatment	At the Beginning	After 30 Days	
Stable	100	20	check	7.7	2.2	0.38
Stable	100	20	heat	0.7	17.7	5.23
Stable	100	20	toluene	2.4	9.0	4.10
Stable	100	30	check	20.6	1.7	1.15
Stable	100	30	heat	15.8	10.4	4.22
Stable	100	30	toluene	15.9	26.7	4.61
Alfalfa	70	out-of-doors	check	19.9	5.6	18.18
Alfalfa	70	out-of-doors	heat	1.9	18.9	24.58
Alfalfa	70	out-of-doors	toluene	1.2	14.5	19.20
Alfalfa	70	20	check	7.7	8.4	11.52
Alfalfa	70	20	heat	0.3	8.9	29.18
Alfalfa	70	20	toluene	9.9	10.2	16.13
Alfalfa	70	30	check	41.3	16.0	12.42
Alfalfa	70	30	heat	4.7	7.3	16.13
Alfalfa	70	30	toluene	35.5	39.5	3.84
Alfalfa	100	20	check	11.5	8.0	6.78
Alfalfa	100	20	heat	0.6	14.0	8.06
Alfalfa	100	20	toluene	8.4	20.2	8.06
None	70	out-of-doors	check	1.5	1.0	0.00
None	70	out-of-doors	heat	0.7	2.9	1.15
None	70	out-of-doors	toluene	0.6	10.6	1.28
None	70	20	check	0.9	1.6	1.02
None	70	20	heat	0.2	2.2	0.90
None	70	20	toluene	0.6	12.4	0.26
None	70	30	check	1.2	2.4	0.13
None	70	30	heat	0.6	3.8	1.02
None	70	30	toluene	1.0	12.2	1.40
None	100	out-of-doors	check	1.9	2.5	0.38
None	100	out-of-doors	heat	0.8	4.1	1.28
None	100	out-of-doors	toluene	2.0	25.6	0.90
None	100	20	check	0.3	1.1	0.64
None	100	20	heat	0.2	2.8	1.02
None	100	20	toluene	0.8	3.2	0.68
None	100	30	check	3.1	3.1	0.90
None	100	30	heat	0.6	18.4	2.04
None	100	30	toluene	1.1	12.5	1.92
Average	.....	....	check	8.6	4.1	3.64
Average	.....	....	heat	1.8	11.3	6.41
Average	.....	....	toluene	5.6	16.7	4.43
Average	.....	out-of-doors	......	[1]6.8	8.5	5.16
Average	.....	20	......	[1]5.4	11.4	5.27
Average	.....	30	......	[1]9.2	12.2	3.50
Average	70	*	......	[1]9.3	11.1	....
Average	100	....	......	[1]7.7	10.3	....

[1] Only checks were used for these averages; in all other cases all soils, treated and untreated, were used for the average.

* Average for ammonia is not given, since the alfalfa soils which gave the largest amounts of ammonia were present in 3 cases for the 70 per cent moisture and only in one case for the 100 per cent moisture. Hence a true average would not be obtained.

per gram; but after proper moisture had been added and the soils allowed to incubate for 30 days, the numbers increased to 11,300,000, almost three times that of the untreated soils. The treatment with toluene also lowered the bacterial numbers; after 30 days' incubation the numbers increased from 5,600,000 to 16,700,000 per gram of soil, more than four times the numbers found in the untreated soils.

This experiment confirms fully the results of Russell and Hutchinson (7, 8) that partial sterilization of soil by heat and antiseptics increases the amount of ammonia produced in the soil and also the bacterial numbers; but this is not due to the destruction of protozoa, since in the case of the toluene treated soils some of the protozoa, namely the flagellates and in some cases small ciliates, were left, while there was an increase in ammonia production and in bacterial numbers. However, the idea expressed by Dr. Löhnis that there might be two kinds of protozoa in the soil, one injurious to bacteria and thus to soil fertility and another non-injurious and perhaps even beneficial, may hold true.

The action of toluene and heat is greatest upon the soils having a high content of undecomposed organic matter; the presence of protozoa does not seem to have any important part to perform here, because the action of antiseptics and heat will be much less in soils having a low content of organic matter, though it may contain protozoa. The reason why most investigators have failed to get results similar to those obtained by Russell and his associates may be due to the fact that they did not work with soils of such a high content of organic matter as Russell and his associates did.

Attention should be called to the fact that in many instances where the soil has been treated with heat and toluene, the fungi were found at the end of 30 days' incubation in much larger numbers than in the checks; since these organisms, as was shown in another place (11), are very strong ammonifyers, the increase in ammonia production may be due not at all to the increase in bacterial numbers, but to the improved conditions for fungus activities. The rapid decomposition of the organic matter by these organisms may lead to increased bacterial activities, so that the beneficial results of the partial sterilization may not be due at all to the destruction of some protozoa, but to the improvement of the soil conditions for the action of microörganisms, such as fungi, which otherwise remain in a not very active stage.

Summary

1. The presence of protozoa seems to check the bacterial numbers, which are found to be smaller in the soils where the protozoa are present than in the corresponding soils where they are absent.

2. The ammonifying efficiency of the soil does not go hand in hand with the changes in bacterial numbers.

3. Heating the soil at 65° C. for 5 hours destroyed the protozoa in all instances but one, and greatly reduced the bacterial numbers; but when proper moisture was added and the soils were allowed to incubate for 30 days, the bacterial numbers increased to almost three times those of the check. There was a corresponding increase in ammonia production in the soil.

4. The action for 48 hours of 4 per cent toluene, which was then allowed to evaporate for 48 hours, killed the ciliates, but not the flagellates; this treatment also reduced the bacterial numbers, but they at once increased after the toluene was allowed to evaporate.

5. The action of toluene and heat is greatest upon soils having a high content of organic matter, whether the protozoa are active or not.

6. The Sassafras soils kept out-of-doors gave higher bacterial numbers and higher ammonifying efficiency than those kept under laboratory temperatures and the latter gave higher numbers and ammonifying efficiency than those kept at 30° C.

7. The soils with the optimum moisture, gave in the main, higher bacterial numbers and ammonifying efficiency than those containing full moisture-holding capacity.

8. There may be two types of protozoa in the soil, one injurious to bacteria and to soil fertility, and the other uninjurious and perhaps even beneficial; the beneficial influence of antiseptics upon soil may be due to the killing of the first type of protozoa.

9. There are, however, other factors, which point out that the improved soil conditions brought about by the action of heat and antiseptics may be due to the improvement of conditions for other organisms, such as fungi, to work in the soil; or the soil itself may be changed in such a manner as to offer new conditions to its microörganic population.

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THE LOESS SOILS OF THE NEBRASKA PORTION OF THE TRANSITION REGION :

V. THE WATER-SOLUBLE CONSTITUENTS[1]

BY

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The following paper presents the results of an investigation of the water-soluble material of the loess soils of the Nebraska portion of the transition region. The general chemical and physical properties of these soils have been dealt with in detail, in papers by Alway, et al (1, 2, 3, 4).
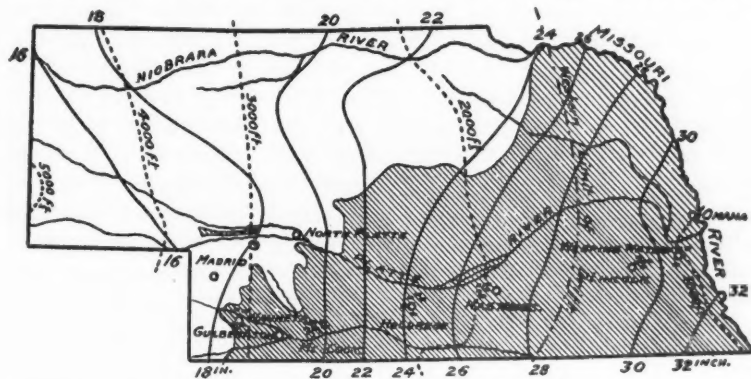
Fig. 1.—Map of Nebraska showing distribution of the loess, precipitation belts, the altitude and the locations of the fields sampled.

In Nebraska the loess soils extend westward from the Missouri river a distance of about 300 miles. Throughout this region the temperature conditions are quite uniform but there is a gradual decrease in the humidity of the climate. The normal annual precipitation which exceeds 30 inches at the eastern boundry, falls steadily until it is less than 20 inches in the extreme western portion, while the rate of evaporation increases considerably. The climate of this region is described in detail by Alway and McDole (3, p. 239).

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[1] Received for publication July 22, 1916.

The soil samples which were used in carrying out the work here re-
ported were collected by Alway and McDole and are the same samples
on which the article, above referred to, is based. They were collected
from 30 virgin prairie fields, five near each of six stations of the Weather
Bureau of the U. S. Department of Agriculture, as shown in the map
(fig. 1)—Wauneta, McCook, Holdrege, Hastings, Lincoln and Weeping
Water. In each field at intervals of 30 feet, ten borings were made to a
depth of 6 feet and composite samples prepared of each foot section, thus
giving six samples from each field, the so-called "field samples." From
these the "area samples" were prepared by mixing equal weights of the
corresponding five "field foot-samples." Thus each of the "area foot-
samples" is a composite from 50 individual borings. The method of sam-
pling is described in detail in the article above referred to.

Determinations of total solids, non-volatile inorganic material, car-
bonic acid, bicarbonic acid, chloride ion, phosphate ion, sulphate ion,
potassium, calcium and magnesium ions were made on each of the "area
foot-samples." The methods employed were those described by
Schreiner and Failyer (6). The solution was obtained by shaking 200
gm. of soil with 500 c.c. of carbon dioxide-free distilled water at 5-min-
ute intervals for 2 hours and allowing to stand over night. The solution
was filtered through a Chamberland-Pasteur porcelain tube in the appara-
tus devised by Briggs (5, p. 31). Total solids were obtained by evapora-
tion of 100 c.c. of this solution to dryness and heating to constant weight
at 110° C. Non-volatile inorganic material was determined by ignition of
the total solids. Bicarbonate was determined by titration with standard
potassium hydrogen sulphate solution, using methyl orange as indicator.
Chlorides were determined in the usual way by titration with standard
silver nitrate. Sulphates and calcium were determined by the turbidity
method (6, p. 19) and phosphates, potash and magnesium by the colori-
metric methods as described by Schreiner and Failyer (6, p. 53).

It should be emphasized that the determination of such small amounts
of material as are present in water extracts of ordinary soils is attended
with unusual experimental difficulties. In the work here reported every
precaution was taken to insure the highest attainable degree of accuracy.
Those reagents which were liable to become contaminated through con-
tact with glass were stored in paraffin containers. In the determination of
any one constituent the same procedure was followed throughout.
Colorimetric and turbidity methods are open to criticism because the per-
sonal equation of the operator is an important factor. Furthermore some
of the estimations by these methods are in themselves only approxima-
tions, whereas some have been so highly perfected that they surpass
gravimetric estimations in accuracy. In the estimation of small amounts
of material such as are found in soil extracts, one is left no choice as to
methods. The colorimetric and turbidity methods used in this work ad-

mit of the determination of small amounts of material such as could not possibly be detected by ordinary gravimetric methods. Thus while the absolute accuracy of some of the results here reported may be questioned, nevertheless we feel that the results are of comparative value and in this respect have a real meaning.

In Table I are given the results of the analyses of the extracts of the "foot samples" from the six different areas. Results are expressed as parts per million of dry soil.

An inspection of the tables brings out first of all the fact that the soils of the Nebraska loess are remarkably uniform as regards their content of water-soluble material. On the whole the study indicates that soils with enough water-soluble material to be regarded as "alkaline" are nowhere to be expected on the prairies of the transition region, except possibly in depressions. The highest amount of total water-soluble material occurs in the first foot of the Lincoln area and the smallest amount in the sixth foot of the Weeping Water area. The bicarbonates seem responsible for the larger part of the inorganic material.

In Table II are given the figures of Table I rearranged for better comparison.

Inorganic Material

As regards total inorganic material the largest amount is found in the sixth foot of the Wauneta area and the smallest amount in the fifth foot of the Weeping Water area. In all the areas excepting the Weeping Water the total inorganic material increases somewhat from the first foot downward, though not in a regular way. The average amount of inorganic material in the six foot-sections decreases quite regularly as we pass from west to east. This is accounted for by the greater rainfall in the eastern areas and the consequent greater amount of leaching.

Bicarbonates

The water-soluble carbon dioxide appeared in the form of bicarbonates entirely, no carbonates being found in the extracts of any of the soils. The water-soluble bicarbonates increase quite regularly from the first foot downward in all of the areas, excepting the Weeping Water. In each of the foot sections they decrease quite regularly as we pass from west to east. They are highest in the third foot of the Hastings area and lowest in the lower sections of the Weeping Water area, being practically zero in the sixth foot. The average amount of bicarbonate decreases quite regularly from west to east, except that in the Hastings area it is slightly higher than in the Holdrege area. Bicarbonates follow the total inorganic material in this respect. The variation in the bicarbonate agrees in general with that of the total carbon dioxide as found by Alway and Rost, (4, p. 114) which averaged 1.49 per cent in the McCook area

TABLE I

WATER-SOLUBLE CONSTITUENTS FROM FOOT SAMPLES OF LOESS SOILS EXPRESSED IN PARTS PER MILLION

WAUNETA AREA

Depth Foot	Total solids	In-organic	HCO$_3$	Cl	K	PO$_4$	SO$_4$	Ca	Mg
1	598	213	173	17	38	20	9	30	8
2	415	203	182	16	36	14	41	24	8
3	310	138	186	6	60	12	2	20	6
4	358	233	195	14	87	5	34	14	3
5	365	253	225	15	71	6	45	17	4
6	398	298	247	21	71	5	64	17	4

McCOOK AREA

Depth Foot	Total solids	In-organic	HCO$_3$	Cl	K	PO$_4$	SO$_4$	Ca	Mg
1	533	150	134	Trace	49	14	Trace	24	7
2	463	195	270	4	60	8	Trace	31	13
3	370	218	225	8	73	9	8	21	6
4	308	183	222	13	60	8	33	11	3
5	378	255	213	21	61	14	71	9	2
6	470	243	206	34	58	10	98	12	2

HOLDREGE AREA

Depth Foot	Total solids	In-organic	HCO$_3$	Cl	K	PO$_4$	SO$_4$	Ca	Mg
1	613	202	107	52	51	17	19	22	10
2	390	145	62	18	36	16	38	14	5
3	370	238	244	9	49	21	27	22	13
4	308	175	188	15	53	26	6	29	6
5	313	168	178	12	41	22	29	22	5
6	313	213	177	16	56	23	36	18	4

HASTINGS AREA

Depth Foot	Total solids	In-organic	HCO$_3$	Cl	K	PO$_4$	SO$_4$	Ca	Mg
1	730	140	95	54	60	10	9	29	12
2	365	83	47	20	31	8	39	15	6
3	440	210	328	13	52	7	29	31	17
4	370	235	261	18	53	8	30	26	11
5	353	185	210	17	49	6	29	21	8
6	293	170	202	21	44	6	28	16	6

LINCOLN AREA

Depth Foot	Total solids	In-organic	HCO$_3$	Cl	K	PO$_4$	SO$_4$	Ca	Mg
1	1188	265	113	36	38	22	41	24	23
2	565	140	54	18	20	13	45	14	11
3	360	95	57	19	18	11	51	10	6
4	425	250	165	28	18	6	83	20	16
5	343	208	194	23	18	6	42	15	12
6	320	205	170	21	20	7	43	12	9

WEEPING WATER AREA

Depth Foot	Total solids	In-organic	HCO$_3$	Cl	K	PO$_4$	SO$_4$	Ca	Mg
1	885	250	88	16	23	12	38	16	10
2	665	155	47	8	17	10	9	10	5
3	328	107	26	10	11	10	13	3	3
4	140	45	9	7	7	12	20	Trace	1
5	110	40	11	8	6	12	18	Trace	1
6	95	85	..	15	11	..	23	..	1

and only 0.02 per cent in the Weeping Water area. Again, the lesser amount of leaching accompanying the lower rainfall would account for the much higher bicarbonate content in the soils of the western areas as compared with those of the eastern.

Chlorides

The water-soluble chlorides are low in all the soils of all the areas and account for but a small portion of the total soluble inorganic material. There is nothing noteworthy about their distribution. Excepting the first foot of the Hastings and Holdrege areas, the distribution of chlorides is quite uniform both as to depth and area.

Potassium

The distribution of the water-soluble potassium is noteworthy. It is highest in the Wauneta and McCook areas and lowest in the Weeping Water area, the average for the six foot-sections being nearly five times as great in the former as in the latter. In the extreme eastern area, the potassium *decreases* in passing from the first to the sixth foot, whereas in the Wauneta area it *increases* from the first foot downward. The intervening areas show an intermediate behavior. The potash in these same soils, soluble in 1 per cent citric acid, was found by Alway and Isham (2, p. 307) to exhibit a similar behavior. On the average it was practically three times as high in the western as in the eastern area. Furthermore it was found to *decrease* from the surface foot downward in the Weeping Water area, the figures being 0.036 per cent and 0.016 per cent for the first and sixth feet respectively with an average of 0.025 per cent for the six feet; whereas in the Wauneta area the citric-acid-soluble potash *increased* from 0.047 per cent in the surface foot to 0.083 per cent in the sixth foot, with an average of 0.071 per cent for the six feet. The intervening areas showed an intermediate behavior as regards their content of potash, soluble in 1 per cent citric acid. This peculiarity in the distribution of the water-soluble and citric-acid-soluble potassium is in striking contrast to the distribution of the total potassium and the potassium soluble in strong acids. Alway and Isham (2, p. 301) found the total, as well as the strong acid-soluble potash, to be quite uniformly distributed in these soils. The average total potash for all the sections of all the areas was 2.54 per cent and in none of the sections of any of the areas does the total potash vary more than 0.21 per cent from this figure. Similar results were obtained for the potash soluble in strong hydrochloric acid. It would seem that the same compounds which are responsible for the citric-acid-soluble potash, are responsible also for the water-soluble potash in these soils.

TABLE II

WATER-SOLUBLE CONSTITUENTS FROM FOOT SAMPLES OF LOESS SOILS
EXPRESSED IN PARTS PER MILLION

Constituents	Depth	Area					
		Wauneta	McCook	Holdrege	Hastings	Lincoln	W. Water
Inorganic .	1	213	150	202	140	265	250
	2	203	195	145	83	140	155
	3	138	218	238	210	95	108
	4	233	183	175	235	250	45
	5	253	255	168	185	208	40
	6	298	243	213	170	205	85
Average ..		223	207	190	170	193	113
HCO_3	1	173	134	107	95	113	88
	2	182	270	62	47	54	47
	3	185	225	244	328	57	26
	4	195	222	188	261	165	9
	5	225	212	178	210	194	11
	6	247	205	177	202	170	..
Average ..		201	211	159	190	125	30
Cl	1	17	..	52	54	36	16
	2	16	4	18	20	18	8
	3	6	8	9	13	19	10
	4	14	13	15	18	28	7
	5	15	21	12	17	23	8
	6	21	34	16	21	21	15
Average ..		15	13	20	24	24	11
K	1	38	49	51	60	38	23
	2	36	60	36	31	20	17
	3	60	73	49	52	18	11
	4	87	60	53	53	18	7
	5	71	61	41	49	18	6
	6	71	58	56	44	20	11
Average ..		60	60	48	48	22	12
PO_4	1	20	14	17	10	22	12
	2	14	8	16	8	13	10
	3	12	9	21	7	11	9
	4	5	8	26	8	6	12
	5	6	14	22	6	6	12
	6	5	10	23	6	7	..
Average ..		10	11	21	7	11	11

TABLE II—(Continued)

WATER-SOLUBLE CONSTITUENTS FROM FOOT SAMPLES OF LOESS SOILS
EXPRESSED IN PARTS PER MILLION

Constitu- ents	Area						
	Depth	Wauneta	McCook	Holdrege	Hastings	Lincoln	W. Water
SO₄	1	9	Trace	19	9	41	38
	2	41	Trace	38	39	45	9
	3	2	8	27	29	51	13
	4	34	33	6	30	83	20
	5	45	71	29	29	42	18
	6	64	98	36	28	43	23
Average ..		32	35	26	27	51	20
Ca	1	30	24	22	29	24	16
	2	24	31	14	15	14	10
	3	20	21	22	31	10	3
	4	14	11	29	26	. 20	Trace
	5	17	9	22	21	15	Trace
	6	17	12	18	16	12	..
Average ..		20	18	21	23	16	..
Mg	1	8	7	10	12	23	10
	2	8	13	5	6	11	5
	3	6	6	13	17	6	3
	4	3	3	6	11	16	1
	5	4	2	5	8	12	1
	6	4	2	4	6	9	1
Average ..		6	6	7	10	13	3
Volatile Matter (Organic)	1	385	383	411	590	923	635
	2	202	268	245	282	425	510
	3	172	152	132	230	265	220
	4	125	125	133	135	175	95
	5	112	123	145	168	135	70
	6	100	227	100	123	115	10
Average ..		182	213	194	255	339	257
Total solids	1	598	533	613	730	1188	885
	2	415	463	390	365	565	665
	3	310	370	370	440	360	328
	4	358	308	308	370	425	140
	5	365	378	313	353	343	110
	6	398	470	313	293	320	95
Average ..		407	420	384	426	533	370

Phosphoric Acid

The water-soluble phosphates on the whole show no regularity in distribution. Considering the amount in the whole six-foot section, they do not increase from west to east as does the water-soluble potash but are similar in amount in the extreme areas, with a somewhat higher content in the central areas, notably in the Holdrege. In the most western area it shows a decrease from the surface downward, whereas in the other areas it shows no very regular distribution. The distribution of the water-soluble phosphoric acid as compared with the phosphoric acid, soluble in 1 per cent citric acid, does not show the striking similarity which is brought out by a comparison of the water-soluble and citric-acid-soluble potash. Alway and Isham (2, p. 307) have shown that the phosphoric acid, soluble in 1 per cent citric acid, is highest in the two central areas and lowest in the two extreme areas. Furthermore it decreased from the surface foot downward in the two most westerly areas, whereas in the extreme eastern area it very markedly increased from the surface downward. The water-soluble phosphoric acid agrees with this only in being somewhat higher in the Holdrege area and in showing some decrease from the surface downward in the Wauneta area. It would seem that the comparative uniformity in the distribution of the water-soluble phosphates is due to the fact that the phosphates of the soil are only slightly water-soluble and that there is present in all these soils more than enough to saturate the water solution.

Sulphates

The distribution of the water-soluble sulphates shows no significant variations. It is on the whole quite uniform, except that sulphates are practically absent in the upper sections of the McCook area and are somewhat higher in the Lincoln area than in any of the others.

Calcium and Magnesium

The water-soluble calcium is distributed very uniformly throughout the different areas except that it is practically absent in the lower levels of the Weeping Water area. Both the total and the acid-soluble calcium were found by Alway and Rost (4, p. 413) to vary with the area, being more than three times as high in the lower levels of the western areas, as in those of the eastern areas. They also increased from the surface foot downward in all the sections. The water-soluble magnesium is even more uniformly distributed than is the calcium and follows the total and acid-soluble magnesium, as determined by Alway and Rost, in this respect.

Volatile Matter

The water-soluble material which is volatile on ignition is chiefly organic matter, with some carbon dioxide from alkaline earth carbonates, and possibly some hydration water and water of constitution.

In general, the distribution of the water-soluble volatile matter agrees with that of the total volatile matter and the organic carbon as determined by Alway and McDole (3, p. 228, 232). It increases quite regularly from west to east, especially in the upper three feet. It furthermore decreases regularly from the surface foot downward in all of the areas, and obviously, is higher in the eastern areas because of the greater amount of vegetative growth.

Total Soluble Material

The distribution of the total water-soluble material is quite uniform when the average of the six sections of the different areas is considered. In the upper sections it increases from west to east, whereas in the lower sections it decreases more or less uniformly. The greater amount of volatile organic matter in the upper sections of the eastern areas together with a greater amount of inorganic material in the lower sections of the western areas accounts for this variation.

SUMMARY

In general the water-soluble material in the loess soils of the Nebraska portion of the transition region is low. The average total water-soluble material is quite uniformly distributed as to area, the inorganic material increases with the aridity, whereas the volatile material decreases with increasing aridity.

The water-soluble bicarbonates decrease from west to east and follow the total carbonates in this respect. The water-soluble chlorides and sulphates as well as calcium and magnesium are quite uniformly distributed and follow the distribution of the total amounts of these constituents, in these same soils.

The water-soluble potassium is highest in the western areas and lowest in the eastern areas. In the extreme eastern area it decreases from the surface downward, whereas in the western area the reverse is true. In this respect it follows the citric-acid-soluble potash and not the total potash, which is quite uniformly distributed.

The water-soluble phosphates show no very regular distribution.

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ON THE DISTRIBUTION OF PHOSPHORUS IN A VERTICAL SECTION OF BLUEGRASS SOIL[1]

By

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The most important chemical action concerned in the disintegration of limestone rock to form soil is the combination of the free carbonic acid contained in natural waters with the calcium carbonate and magnesium carbonate of the limestone to form calcium and magnesium bicarbonate, substances soluble in water [$CaCO_3 + H_2CO_3 = CaH_2(CO_3)_2$]. Thus the calcium and magnesium carbonates, which compose the greater part of most limestones, may be dissolved and carried away by percolating water, leaving behind the less easily soluble constituents of the limestone, such as sand, clay and other silicates, ferric oxid, etc. It is this residue of nearly insoluble material which finally becomes converted into soil. In regions of abundant rainfall, such as our Bluegrass country, this disintegration of the limestone and addition of the residuum to the soil is going on almost continuously at the surface of the rock beneath the soil. The rain water, as it falls upon the ground, already contains a little dissolved carbon dioxide derived from the air. In sinking through the soil it acquires more from the oxidation of organic matter in the soil. While passing through the soil, the water takes up more or less soluble material until its downward passage is arrested by the underlying limestone. Here the water may be supposed to collect for a time and be in contact with the limestone long enough to become fully saturated with calcium carbonate before it finds its way to the surface of the ground, at some lower point, in the form of a spring. Such waters carry in solution, besides calcium and magnesium bicarbonate, appreciable quantities of sodium, potassium, iron, silica, sulfates, chlorids, nitrates and phosphates, showing that even the less soluble or soil-making substances are attacked to some extent. The amount of phosphate carried away by the water of springs has recently been studied by Mr. J. S. McHargue, of the Kentucky Agricultural Experiment Station, and reported upon in a paper read at the 1915 meeting of this Academy. Mr. McHargue's analyses show that this amount is relatively small, as compared with the amount of calcium and magnesium

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carbonate present in these waters. The average from the analyses of the water of six different springs in Fayette and Woodford Counties shows one part of tricalcium phosphate to about 100 parts of calcium and magnesium carbonates, taken together, the extremes being 1:71, and 1:133. This phosphate may have been taken up either from the soil through which the water has percolated or from the limestone with which it has come in contact, or both. The relatively small solubility of tricalcium phosphate leads to the inference that, when a highly phosphatic limestone is acted upon by natural waters, the greater part of the phosphate contained in the limestone will be left in the resulting soil, after practically all the calcium carbonate has been dissolved away. Thus, if there is in a given limestone more than one part of tricalcium phosphate to 100 parts of calcium and magnesium carbonates, the excess of phosphate would remain undissolved and be added to the soil. The distribution of phosphorus in a column of soil, however, must be affected by the phosphate continuing to go into solution after all carbonate has been removed, thus reducing the amount in the upper part of the column. Again, in a very phosphatic soil, the fact that the percolating water has an opportunity to become saturated with phosphate before reaching the bed rock would greatly diminish or wholly nullify its solvent action upon the phosphate of the underlying limestone, thus tending all the more to preserve in the newly made soil at the bottom of the column the differences in phosphate content existing in the original limestone.

There are numerous analyses which show that the several layers of the limestone underlying the soil in the vicinity of Lexington differ greatly with regard to their phosphorus content. Published analyses give percentages of phosphorus ranging from 0.3 or less to about 14 per cent, the latter being in a very thin layer of limestone. The ratio of tricalcium phosphate to calcium and magnesium carbonate ranges from 1:60 to 1:1, or, from 1 2/3 parts to about 100 parts of phosphate to every 100 parts of carbonate. The natural inference from these facts and the considerations already stated is that when such limestones, lying in horizontal strata, are converted into soil by natural processes, there would result a soil having horizontal bands of very different phosphorus content, corresponding in a rough way to the several layers of the original limestone, and that these differences would be best preserved in the lower part of the column where the soil is comparatively new.

A series of samples, taken vertically through such a soil, should contain very different proportions of phosphorus. To test this hypothesis, several borings were made on the Experiment Station farm at Lexington, some years ago, by the writer, assisted by Mr. Robert Hart. The soil from each six inches was stored separately and analyzed for phosphorus by Mr. O. M. Shedd, of the Experiment Station. A graphical representation of results of two of these borings is presented herewith. The dif-

ferences shown are just such as would be expected in a soil derived from the highly phosphatic layers of the Lexington limestone and they appear to even a more marked degree than was anticipated. It may be added that small pieces of nearly pure, soft phosphate could be distinguished in several of the samples.

It has been argued that some of the phosphate taken by the soil water from the upper part of the soil column may be deposited again when the lower part of the column is reached, where calcium carbonate is still present in effective quantity. The fact that tricalcium phosphate is less soluble in carbonated water in the presence of calcium carbonate than it is if calcium carbonate is absent, would favor this view. Such a process would tend to produce a maximum of phosphate at a short distance above the bed rock, as was found in the first boring; it would hardly account for the existence of two maxima, as found in the second boring. Besides, the large percentages and the magnitude of the differences found suggest strongly that the distribution of the phosphate in the limestone before it became soil, is the controlling factor, even if leaching and redeposition of phosphate has played some part. The fact that plates of phosphate similar to those occurring in the limestone may be found in the more phosphatic parts of the soil column supports this view.

It should be stated in this connection, also, that the amount of calcium carbonate in this soil is small. Analyses by Dr. Blumenthal of this Station on the soil from the first boring show the maximum of 0.135 per cent of calcium carbonate in the third six inches above the rock and the minimum 0.020 per cent in the fourth sixth inches from the top.

In comparing the two diagrams, it is important to bear in mind that the first boring was made near the top of a gentle slope, whereas, the second was near the bottom of such a slope, a slight rise intervening between the two. No doubt some of the older and well leached soil has been removed from the top of the first column, a condition which would account for the high percentage of phosphorus in the first foot, and that soil of a similar character has been added to the top of the second column, thus keeping down the phosphorus content in the upper four feet.

Both borings were started on nearly level ground at approximately the same elevation above sea level, namely, between 990 and 995 feet, as nearly as could be judged from the 5-foot contour lines on the map of the farm.

These considerations suggest that the maximum phosphate in the first diagram and the first maximum in the second should be referred to the same highly phosphatic beds in the original limestone.

It may not be without interest in this connection to speculate a little upon the character and thickness of a section of limestone capable of producing a soil section similar to that described, though it would be impossible to arrive at a definite or exact conclusion, from the data available. Of

PER CENT OF PHOSPHORUS

Depth	Per cent P	0	1%	2%	3%	4%	5%	6%	7%	8%
	0.76									
1 ft.	0.72									
	0.94									
2 ft.	1.07									
	1.52									
3 ft.	2.69									
	3.24									
4 ft.	4.08									
	4.71									
5 ft.	5.45									
	5.09									
6 ft.	7.80									
	4.03									
7 ft.	2.02									

Underlying limestone

Depth	Per cent P									
	0.29									
1 ft.	0.26									
	0.26									
2 ft.	0.30									
	0.35									
3 ft.	0.37									
	0.39									
4 ft.	0.47									
	0.46									
5 ft.	0.60									
	0.91									
6 ft.	1.53									
	3.10									
7 ft.	4.35									
	6.29									
8 ft.	5.37									
	5.27									
9 ft.	6.53									
	6.57									
10 ft.	6.69									
	3.34									
11 ft.	2.23									
	1.11									
12 ft.	2.93									
	5.38									
13 ft.	4.21									
	1.02									
14 ft.	1.53									
	1.74									
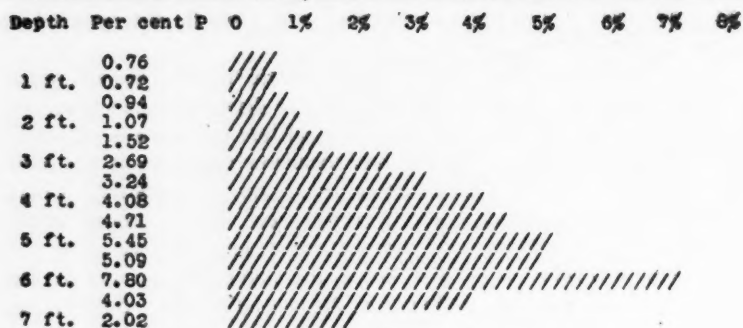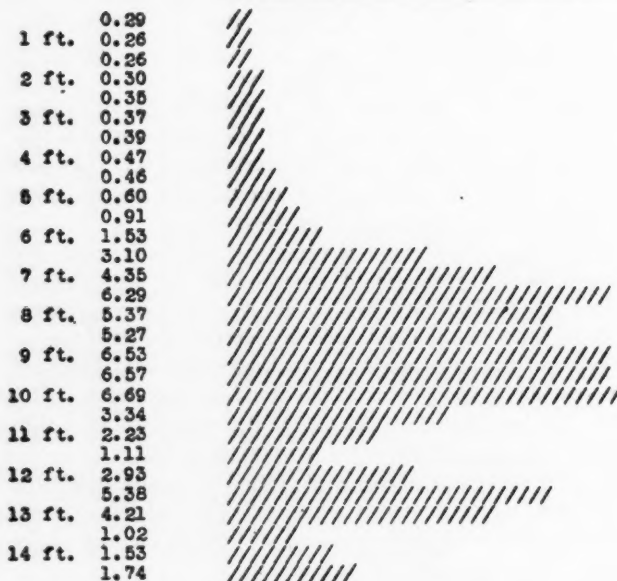
Underlying limestone

Fig. 1.—Phosphorus in soil sections, Experiment Station Farm, Lexington, Ky.
Top, Rose St. field, top of gentle slope.
Bottom, forage plots, bottom of gentle slope.
Elevation of the top of each, between 990 and 995 ft. above sea level. The two points are about 250 yards apart.
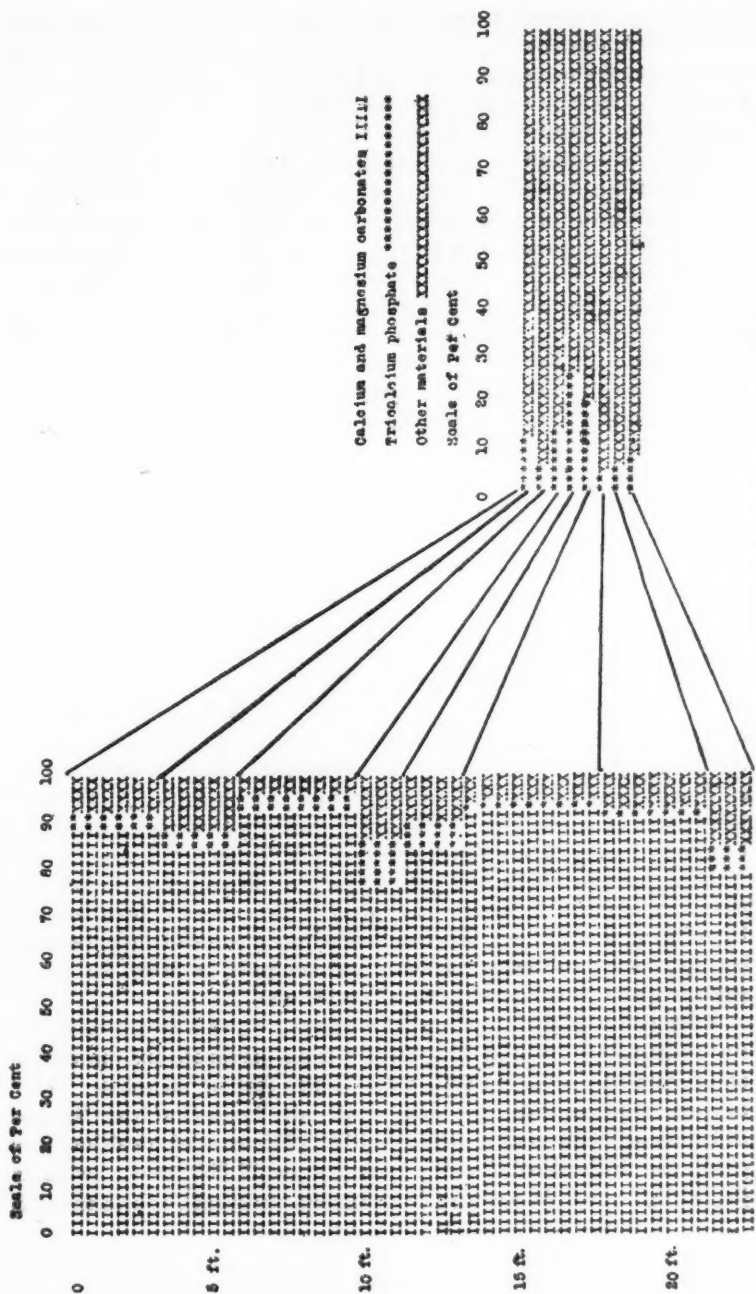
Fig. 2.—Hypothetical section of limestone with the corresponding soil.

great assistance in such a speculation would be a series of separate analyses of each consecutive layer in a vertical section covering a considerable thickness of the more phosphatic part of the Lexington limestone. Unfortunately, no such series of analyses has been made. In the chemical reports of the Kentucky Geological Survey, Dr. Robert Peter published phosphate determinations upon samples of limestone taken from several different layers exposed in the face of the McMeekin quarry on the Newtown road 4 miles north of Lexington, where he first discovered the phosphate, but the thickness of only one layer was reported. This was the principal phosphatic layer, about a foot thick, appearing at the bottom of the quarry face. Analyses of a sample from this layer gave 45.9 per cent of tricalcium phosphate, 49.2 per cent of calcium carbonate, including a little magnesium carbonate, and 4.9 per cent of other materials. The analyses of eleven other samples selected from different parts of this quarry face gave amounts of tricalcium phosphate ranging from 11.0 per cent to 47.9 per cent, the last being from a thin layer. It is evident that, in taking these samples, the more phosphatic layers were selected. Interspersed with these there must have been layers with a much smaller phosphate content. As the amount of carbonate in the other samples was not determined, we will try to estimate the result of the action of carbonated water upon the 12-inch layer of phosphatic limestone first mentioned. During the solution and removal of 49.2 parts of calcium carbonate by the process heretofore described, about 0.5 part of tricalcium phosphate will have been dissolved. Deducting this from the 45.9 parts present leaves 45.4 parts of tricalcium phosphate, with which will remain the 4.9 parts of other materials belonging to the limestone, making 50.3 parts of residuum, containing 90 per cent of tricalcium phosphate. This would be a high-grade phosphate, somewhat better than the richest plates of phosphate which have been picked out of the highly phosphatic soil corresponding to the geological horizon in which this quarry is situated.

We have here supposed a case where the solvent action on the phosphate was arrested as soon as all calcium carbonate had been removed. Under natural conditions, leaching would continue indefinitely, removing both phosphate and other materials and probably lowering the relative amount of phosphate in the residue considerably.

To obtain a residue more of the nature of soil, we may suppose a limestone containing less phosphate, more calcium carbonate and more of the other materials. For example, with 6.5 per cent of phosphate, 78.5 of calcium carbonate and 15.5 of other materials, the residue from 100 parts of limestone would consist of (6.5—.785) 5.715 parts of tricalcium phosphate and 15.5 parts of other materials, or 21.215 parts, containing $\left(\frac{5.715 \times 100}{21.215}\right)$ about 27 per cent of tricalcium phosphate, equivalent to 5.3

per cent of phosphorus, or about the same as was found in the fifth six inches from the bottom of the second soil section.

To estimate how much of such a limestone would be required to produce a foot of soil, it is necessary to take into consideration the relative weights of limestone and soil. A cubic foot of limestone weighs about 163 pounds and a cubic foot of soil, about 92 pounds. The weight of a cubic foot of limestone, multiplied by the weight of undissolved phosphate and other materials from one pound of limestone ($163 \times .21215$) gives the weight of residuum from a cubic foot of the stone (34.58). Dividing the weight of a cubic foot of soil, by this figure $\left(\frac{92.}{32.58}\right)$ gives the number of cubic feet of limestone required to produce a cubic foot of soil (2.7 cu. ft.) The same figures will represent the thickness of limestone, in feet, necessary to produce one foot of soil on equal areas.

Making the calculation, the result is found to be 2.7 cubic feet; or, it would require approximately a foot and a half of this stone to produce the 6-inch layer of soil in the soil section referred to. The second diagram shows a hypothetical section of limestone which would produce layers of soil corresponding to those found in the lowest four feet of the second section. This part was selected for illustration because it is presumably the newest and least affected by leaching subsequent to the removal of the carbonates.

It is not intended to assert here that the actual section of limestone from which this soil came was constituted as here pictured. An infinite variety of arrangements could be assumed to produce the same result. The problem is indeterminate, from the data at hand.

SUMMARY

The chief object of this paper is to draw attention to the peculiar distribution of the phosphate in these soil sections and to point out that it corresponds strikingly with the distribution of phosphate in the phosphatic limestone beds of this vicinity.

STATEMENT